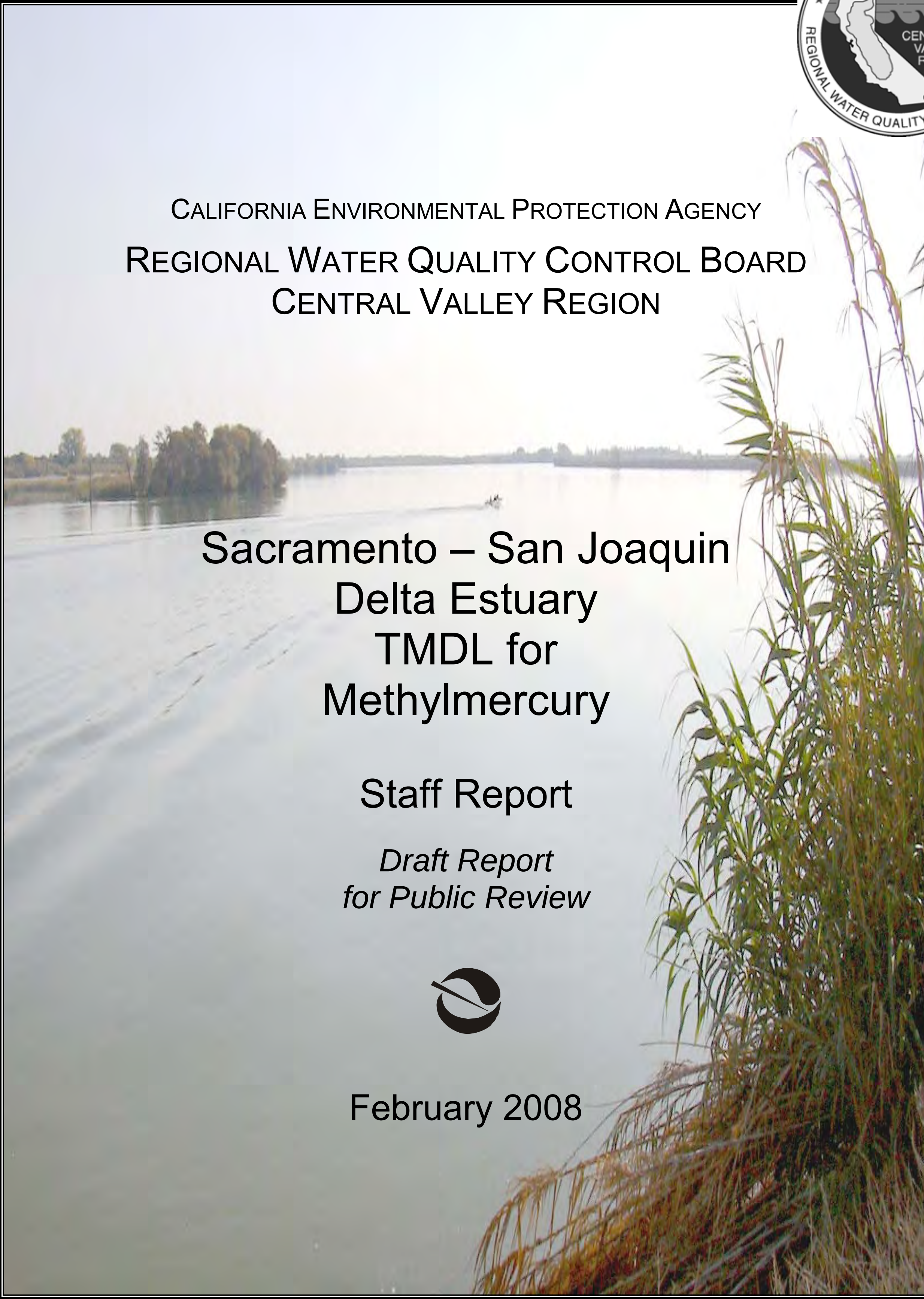

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury

Staff Report

Draft Report for Public Review

February 2008

11020 Sun Center Drive #200
Rancho Cordova, California 95670-6114

Phone: (916) 464-3291

eMail: info5@waterboards.ca.gov
Web site: http://www.waterboards.ca.gov/centralvalley/

DISCLAIMER

This publication is a technical report by staff of the California Regional Water Quality Control Board, Central Valley Region.
The Central Valley Water Board has not adopted or approved of the

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury

Staff Report

Draft Report
for Public Review

February 2008

REPORT PREPARED BY:

Michelle L. Wood
Chris G. Foe, Ph.D.
Janis Cooke, Ph.D.
Stephen J. Louie
David H. Bosworth

ACKNOWLEDGEMENTS

Central Valley Water Board staff gratefully acknowledges the valuable sampling, analytical and administrative support from: Greg Marquis, Taro Murano and Dana Thomsen (former staff with the Mercury TMDL Unit) and Helena Kulesza, Andy Alexander, and Kelly Long (Student Interns).

In addition, this report greatly benefited from the ideas and data generated by:
Carrie Austin, Bill Johnson, Richard Looker (San Francisco Bay RWQCB);
Jay Davis, Ben Greenfield, Jon Leatherbarrow and Lester McKee (San Francisco Estuary Institute);
Mark Stephenson, Wes Heim and Amy Byington (Moss Landing Marine Laboratories);
David Schoellhamer (USGS); Dan Russell (USFWS); Tom Schroyer (CDFG);
Darell Slotton, Shaun Ayers, and Fraser Shilling (University of California, Davis); Stephen McCord (Larry Walker Associates); Khalil Abu-Saba (Brown & Caldwell); and Tom Grieb (Tetra Tech, Inc.).

SACRAMENTO – SAN JOAQUIN DELTA ESTUARY TMDL FOR METHYLMERCURY

Draft Staff Report for Public Review

EXECUTIVE SUMMARY

This draft report presents California Regional Water Quality Control Board, Central Valley Region (Central Valley Water Board) staff recommendations for establishing a Total Maximum Daily Load (TMDL) for methylmercury in the Sacramento-San Joaquin Delta Estuary (the Delta). The report contains an analysis of the mercury impairment, a review of the primary sources, a linkage between methylmercury sources and impairments, and recommended mercury reductions to eliminate the impairment.

This TMDL report is the first component in the Central Valley Water Board's water quality attainment strategy to resolve the mercury impairment in the Delta. The second component is implementing a control program through amendments to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (the Basin Plan), as described in the proposed Basin Plan amendments and text in the draft Basin Plan Amendment staff report.

Scope, Numeric Targets & Extent of Impairment

In 1990 the Central Valley Water Board identified the Delta as impaired by mercury because fish had elevated levels of mercury that posed a risk for human and wildlife consumers. As a result, the Delta methylmercury TMDL addresses all waterways within the legal Delta boundary. In addition, the San Francisco Bay Regional Water Quality Control Board (San Francisco Water Board) identified Central Valley outflows *via* the Delta as one of the principal sources of total mercury to San Francisco Bay and, in its 2006 mercury TMDL for San Francisco Bay, assigned the Central Valley a load reduction of 110 kg/yr. Therefore, the final mercury TMDL control plan for the Delta must ensure protection of human and wildlife health in the Delta and meet the San Francisco Bay TMDL load allocation for the Central Valley.

This TMDL report addresses both methyl and total mercury sources. Reductions in ambient aqueous methylmercury and methylmercury sources are required to reduce methylmercury concentrations in fish. The methylmercury linkage and source analyses divide the Delta into eight subareas based on the hydrologic characteristics and mixing of the source waters. Because the Yolo Bypass acts as a substantial source of methylmercury and total mercury to the Delta, the entire Yolo Bypass was included in the Yolo Bypass subarea. The Yolo Bypass is a 73,300-acre floodplain on the west side of the lower Sacramento River, about two thirds of which is within the legal Delta boundary.

A separate methylmercury allocation scheme was developed for each subarea because the levels of impairment and the methylmercury sources in the subareas are substantially different. Reductions in total mercury loads are needed to reduce aqueous methylmercury in the Delta, to maintain compliance with the USEPA's criterion of 50 ng/l, and to comply with the San Francisco Bay mercury control program.

The concentration of methylmercury in fish tissue is the type of numeric target selected for the Delta methylmercury TMDL. Acceptable fish tissue levels of methylmercury for the trophic level (TL) food groups consumed by piscivorous wildlife species (that is, species that feed on fish) were calculated using a method developed by the U.S. Fish and Wildlife Service that uses daily intake levels, body weights and consumption rates. Numeric targets were developed to protect humans in a manner analogous to targets for wildlife using a method approved by the U.S. Environmental Protection Agency and Delta-specific information.

Three numeric targets are recommended for the protection of humans and piscivorous wildlife: 0.24 mg/kg (wet weight) in muscle tissue of large[1] trophic level four (TL4) fish such as bass and catfish; 0.08 mg/kg (wet weight) in muscle tissue of large TL3 fish such as carp and salmon; and 0.03 mg/kg (wet weight) in whole TL2 and TL3 fish less than 50 mm in length. The targets for large TL3 and TL4 fish are protective of (a) humans eating 32 g/day (8 ounces, uncooked fish per week) of commonly consumed, large fish; and (b) all wildlife species that consume large fish. The target for small TL2 and TL3 fish is protective of wildlife species that consume small fish.

Elevated fish methylmercury concentrations occur along the periphery of the Delta while lower body burdens occur in the central Delta. Concentrations are greater than recommended as safe by the USFWS for wildlife in all subareas except in the Central Delta subarea. The Central Delta subarea requires no reduction to meet the proposed large TL3 fish target for human protection and an 8% reduction to meet the proposed large TL4 fish target for human protection. Percent reductions in fish methylmercury levels ranging from 0% to 75% in the peripheral Delta subareas will be needed to meet the numeric targets for wildlife and human health protection.

Linkage

The Delta linkage analysis focuses on the comparison of methylmercury concentrations in water and biota. Statistically significant, positive correlations have been found between aqueous methylmercury and aquatic biota, indicating that methylmercury levels in water may be one of the primary factors determining methylmercury concentrations in fish.

The Delta TMDL linkage focuses on the correlation between aqueous methylmercury and largemouth bass methylmercury because (1) largemouth bass was the only species systematically collected near many of the aqueous methylmercury sampling locations used to develop the methylmercury mass balance for the Delta (next section) and (2) largemouth bass is a useful bioindicator of spatial variation in mercury accumulation in the aquatic food chain because it maintains a localized home range and has a high trophic position in the Delta food web. It was possible to describe the recommended fish tissue targets in terms of the mercury concentration in standard 350 mm largemouth bass. A methylmercury concentration of 0.28 mg/kg in 350 mm largemouth bass is equivalent to the target of 0.24 mg/kg for large TL4 fish. A methylmercury concentration of 0.24 mg/kg in 350 mm largemouth bass is equivalent to the target of 0.08 mg/kg for TL3 fish. A methylmercury concentration of 0.42 mg/kg in 350 mm largemouth bass is equivalent to the target of 0.03 mg/kg for small fish. The methylmercury

[1] Large fish are defined as 150-500 mm total length or legal catch length if designated by CDFG.

concentration of 0.24 mg/kg in bass predicted for the TL3 fish tissue target is the lowest of the bass values predicted for the three fish tissue targets and is therefore most likely protective of both human and wildlife consumers of higher and lower trophic level fish in the Delta. As a result, a methylmercury concentration of 0.24 mg/kg in 350 mm largemouth bass is referred to as the recommended implementation goal for largemouth bass.

The mercury concentrations in standard 350-mm largemouth bass for each Delta subarea were regressed against the average unfiltered methylmercury concentrations in water in each Delta subarea. Substitution of the recommended implementation goal for largemouth bass (0.24 mg/kg) into the equation developed by this regression results in a predicted, average safe methylmercury concentration in ambient water of 0.066 ng/l. Incorporation of an explicit margin of safety of about 10% results in the recommended implementation goal for unfiltered ambient water of 0.06 ng/l methylmercury. This implementation goal would be applied as an annual average methylmercury concentration in ambient waters of the Delta. The recommended implementation goal is currently met in the Central Delta subarea and nearly met in the West Delta subarea.

Sources – Methylmercury

Average annual methylmercury inputs and exports were estimated for water years (WY) 2000 to 2003, a relatively dry period that encompasses the available information. Sources of methylmercury in Delta waters include tributary inputs from upstream watersheds and within-Delta sources such as methylmercury flux from wetlands and from in-channel sediments, municipal and industrial wastewater, agricultural drainage, and urban runoff. Losses include water outflow to San Francisco Bay, exports to southern California, removal of dredged sediments, photodegradation, uptake by biota, and unknown loss term(s). Figure 1 illustrates the average daily methylmercury imports to and exports from the Delta and Yolo Bypass. Methylmercury flux from wetland and open water sediments within the Delta and Yolo Bypass accounts for about 35% of methylmercury inputs to the Delta/Yolo Bypass. Tributaries contribute about 58% of the Delta/Yolo Bypass methylmercury inputs. The difference between the sum of known inputs and exports is a measure of the uncertainty of the loading estimates and of the importance of other unknown processes at work in the Delta. The sum of known water inputs and exports for WY2000-2003 balances to within about 5%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget for WY2000-2003 does not balance. Average annual methylmercury inputs and exports were approximately 14.3 g/day (5.2 kg/yr) and 6.7 g/day (2.5 kg/yr), respectively (Figure 1). Exports were only about 50% of inputs, indicating that the Delta acts as a net sink for methylmercury. Preliminary photodegradation study results for the Sacramento River near Rio Vista (Byington *et al.*, 2005) suggest that methylmercury loss from photodegradation may account for more than 50% of the unknown loss rate illustrated in Figure 1.

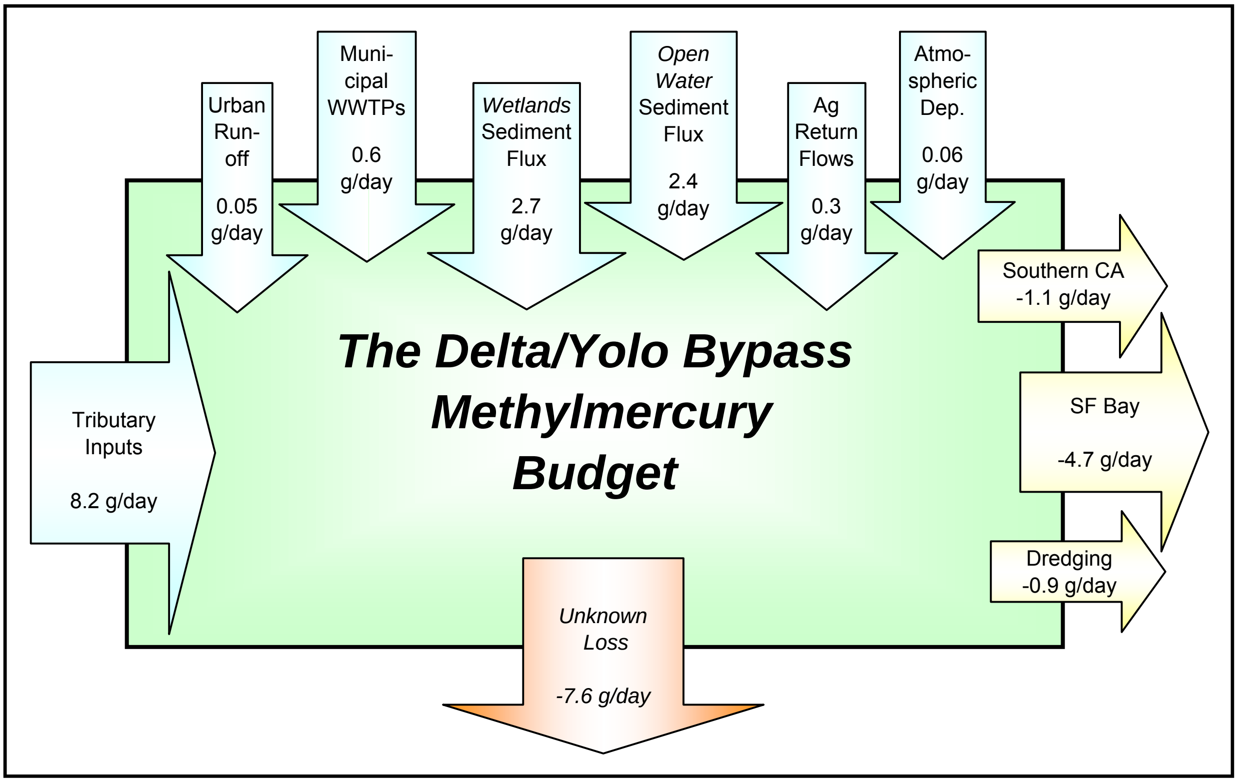

Figure 1: Average Daily Methylmercury Inputs to and Exports from the Delta/Yolo Bypass.

Sources – Total Mercury & Suspended Sediment

Sources of total mercury in the Delta and Yolo Bypass include tributary inflows from upstream watersheds, atmospheric deposition, urban runoff, and municipal and industrial wastewater. More than 97% of identified total mercury loading to the Delta/Yolo Bypass comes from tributary inputs; within-Delta sources are a very small component of overall loading. Losses include outflow to San Francisco Bay, water exports to southern California, removal of dredged sediments, and evasion.

The Sacramento Basin, which is comprised of the Sacramento River and Yolo Bypass tributary watersheds, contributes 80% or more of total mercury fluxing through the Delta. Of the watersheds in the Sacramento Basin, the Cache Creek and upper Sacramento River (above Colusa) watersheds contribute the most mercury. The Cache Creek, Feather River, American River, and Putah Creek watersheds in the Sacramento Basin have both relatively large mercury loadings and high mercury concentrations in suspended sediment, which makes these watersheds more likely candidates for load reduction programs.

Methylmercury Allocations & Total Mercury Limits

Methylmercury allocations were made in terms of the existing assimilative capacity of the different Delta subareas. To determine how much methylmercury in ambient Delta waters need to be reduced to achieve the proposed fish targets, the existing average methylmercury concentration in water in each Delta subarea was compared to the proposed methylmercury goal for ambient water (0.06 ng/l). The amount of reduction needed in each subarea is expressed as a percent of the ambient concentration. Percent reductions required in order to meet the goal ranged from 0% in the Central Delta subarea to about 80% in the Yolo Bypass and Mokelumne River subareas.

In order to achieve the proposed fish targets in each Delta subarea, loads of methylmercury from within-Delta point and nonpoint sources and tributary inputs need to be reduced in proportion to the desired decrease in concentrations needed for ambient waters to meet the proposed goal. The percent reductions and allocations were calculated as percentages of existing loads. The percent reductions vary by subarea because the percent reductions required for ambient water methylmercury levels in each subarea to meet the proposed methylmercury goal vary. No reductions were recommended for sources to the Central and West Delta because the fish and water methylmercury levels achieve or almost achieve the proposed numeric targets and implementation goals, and because methylmercury levels are expected to decrease in these subareas as control actions take place upstream. Percent reductions were applied to point and nonpoint source loads within other subareas, except those sources with existing average methylmercury concentrations at or below the proposed methylmercury goal of 0.06 ng/l. No individual point source would be expected to reduce its discharged methylmercury concentrations to below the proposed implementation goal (or, for nonpoint sources, above their intake water methylmercury concentrations).

A total mercury load reduction strategy was developed to comply with the San Francisco Bay mercury control program, to maintain compliance with the USEPA's criterion of 50 ng/l, and to help reduce aqueous methylmercury in the Delta. Staff recommends total mercury load reductions from the Cache Creek, Feather River, American River, and Putah Creek watersheds in the Sacramento Basin to achieve the total mercury load reduction of 110 kg/yr required by the San Francisco Bay mercury control program. These watersheds have both relatively large mercury loadings and high mercury concentrations in suspended sediment, which makes these watersheds more likely candidates for load reduction programs.

The methylmercury allocations and total mercury limits described in this report reflect the preferred implementation alternative described in Chapter 4 of the draft Basin Plan Amendment staff report and are designed to address the beneficial use impairment in all subareas of the Delta and San Francisco Bay. However, as described in the draft Basin Plan Amendment staff report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of mercury reduction strategies and implementation alternatives as part of the Basin Plan amendment process. All Central Valley Water Board regulatory actions will be taken during public hearings.

SACRAMENTO – SAN JOAQUIN DELTA ESTUARY TMDL FOR METHYLMERCURY

Draft Staff Report for Public Review

TABLE OF CONTENTS

TABLE OF CONTENTS, *continued*

TABLE OF CONTENTS, *continued*

LIST OF APPENDICES

LIST OF TABLES

LIST OF TABLES, *continued*

LIST OF TABLES, *continued*

LIST OF FIGURES

LIST OF FIGURES, *continued*

ACRONYMS

§	Section
ARB	California Air Resources Board
AWQC	Ambient water quality criterion
BAF	Bioaccumulation factor
Basin Plan	Central Valley Region Water Quality Control Plan for the Sacramento River and San Joaquin River Basins
bwt	Body weight
CCSB	Cache Creek Settling Basin
CDEC	California Data Exchange Center
CDFG	California Department of Fish and Game
CDHS	California Department of Health Services, re-organized in 2007 and renamed "California Department of Health" (CDPH). Reports issued before the 2007 re-organization are cited as "CDHS" reports.
CDPH	California Department of Health
CEIDARS	California emission inventory department and reporting system
cfs	Cubic feet per second
CFSII	Continuing survey of food intake by individuals
CMP	Coordinated Monitoring Program
CSS	Combined Sewer system
CTR	California Toxics Rule
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board (a.k.a. Central Valley Water Board)
CWA	Federal Clean Water Act
df	Degrees of freedom (for statistical analyses)
DMC	Delta Mendota Canal
DTMC	Delta Tributaries Mercury Council
DWR	California Department of Water Resources
EC	Electrical conductivity
FCM	Food chain multipliers
GIS	Geographic Information System
HCI	Hydrologic Classification Index
Hg	Mercury
IEP	Interagency Ecological Program
IRIS	Integrated Risk Information System
LMB	Largemouth bass
LOAEC's	Lowest observed adverse effect concentrations
MCL	California/USEPA drinking water standards maximum contaminant levels
MDN	Mercury Deposition Network
mgd	Million gallons per day
MeHg	Monomethyl mercury (also referred to as methylmercury in this report)
MS4	Municipal Separate Storm Sewer System

ACRONYMS, *continued*

NA	Not applicable
NADP	National Atmospheric Deposition Program
NAS	National Academy of Sciences
NEMD	Natomas East Main Drain
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source
NWI	National Wetland Inventory
O	Oxygen
o/oo	Parts per thousand (salinity)
OBS	Optical back scatter
OEHHA	Office of Environmental Health Hazard Assessment
RFD	Reference dose
RSC	Relative source contribution
San Francisco Water Board	San Francisco Bay Regional Water Quality Control Board
SFBADPS	San Francisco Bay Atmospheric Deposition Pilot Study
SFEI	San Francisco Estuary Institute
SRCSD	Sacramento Regional County Sanitation District
SRWP	Sacramento River Watershed Program
State Board	State Water Resources Control Board (also shown as SWRCB in reference citations)
Subwatershed	Portion of watershed that is either upstream or downstream of the most-downstream major dam
SWIM	Surface water information
SWP	State water project
SWRCB	State Water Resources Control Board
TDSL	Total diet safe level
TL	Trophic level
TLR	Trophic level ratios
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USFDA	U.S. Food and Drug Administration.
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
ww	Wet weight concentration (e.g., for fish tissue mercury concentrations)
WWTP	Wastewater treatment plants
X2	Location in the Estuary with 2-o/oo bottom salinity

UNITS OF MEASURE

µg	microgram
µg/g	microgram per gram
µg/l	microgram per liter
µm	micrometer
cfs	cubic feet per second
cm	centimeter
g	Gram
g/day	gram per day
g/l	gram per liter
in/yr	inches per year
kg	kilogram
l	liter
m	meter
mg	milligram
mg/g	milligram per gram
ml	milliliter
mm	millimeter
ng	nanograms
ng/l	nanograms per liter
o/oo	parts per thousand (salinity)
ppb	parts per billion; usually µg/kg
ppm	parts per million; usually mg/kg or µg/g
ppt	parts per trillion; usually ng/kg

1 INTRODUCTION

This draft report presents Central Valley Regional Water Quality Control Board (Central Valley Water Board) staff recommendations for establishing a Total Maximum Daily Load for methylmercury in the Sacramento-San Joaquin Delta Estuary (Figure 1.1). The report contains an analysis of the mercury impairment, a discussion of the primary sources, a linkage between sources and impairments, and recommended methyl and total mercury reductions to eliminate the impairment. The report is one component in the Central Valley Water Board's water quality attainment strategy to resolve the mercury impairment in the Delta.

The Federal Clean Water Act (CWA) requires States to identify water bodies that do not meet their designated beneficial uses and to develop programs to eliminate impairments. States refer to the control program as a Total Maximum Daily Load (TMDL) program. A TMDL is the total maximum daily load of a pollutant that a water body can assimilate and still attain beneficial uses. The Central Valley Regional Water Quality Control Board determined in 1990 that the Delta was impaired because fish had elevated levels of mercury that posed a risk for human and wildlife consumers. In addition, the San Francisco Bay Regional Water Quality Control Board (San Francisco Water Board) identified Central Valley outflows via the Delta as one of the principal sources of total mercury to San Francisco Bay and assigned the Central Valley a load reduction (Johnson and Looker, 2004). Therefore, the final mercury TMDL control plan for the Delta must ensure protection of human and wildlife health in the Delta and meet the San Francisco Bay load allocation to the Central Valley.

In order to meet State and Federal requirements, the TMDL development process must include compiling and considering available information and appropriate analyses relevant to defining the impairment, identifying sources, and assigning responsibility for actions to resolve the impairment. This report has the following sections that reflect the key elements of the Delta methylmercury TMDL development process:

- <u>Chapter 2 – Problem Statement</u>: Presents information that explains the overall regulatory framework for this TMDL, lists future milestones and describes the extent of mercury impairment in the Delta.
- <u>Chapter 3 – Controllable Processes</u>: Describes the methylation processes that are potentially controllable in the Delta. The concepts summarized in this chapter guided the development of the methylmercury TMDL for the Delta, particularly the linkage analyses (Chapter 5), methyl and total mercury source analyses (Chapters 6 and 7), and methylmercury allocation and implementation strategies described in Chapter 4 of the draft Basin Plan Amendment staff report.
- <u>Chapter 4 – Numeric Targets</u>: Proposes numeric targets for fish, which, if met, would protect beneficial uses of Delta waters.
- <u>Chapter 5 – Linkage Analysis</u>: Describes the mathematical relationship between aqueous methylmercury concentrations and the proposed numeric targets for fish mercury levels, which is used to determine an aqueous methylmercury goal that guides the allocation of methylmercury source reductions within the statutory Delta boundary and its tributary watersheds.

- Chapters 6 & 7 – Source Assessment: Identifies and quantifies concentrations and loads of methyl and total mercury sources.
- Chapter 8 – Allocations: Presents recommended methylmercury allocations and total mercury limits for Delta sources to reduce methylmercury concentrations in fish and to comply with the USEPA's CTR and the San Francisco Bay Mercury TMDL allocation for total mercury leaving the Central Valley watershed. This chapter also describes the margin of safety afforded by the analyses' uncertainties and consideration of seasonal variations.

Since the June 2006 draft TMDL Report issued for scientific peer review, staff made several changes to the TMDL Report in response to comments made by the scientific peer reviewers and other agencies and stakeholders:

- Expansion of the numeric target evaluation (Chapter 4) to include results from recent interviews of local community-based groups and pilot surveys and recent final and draft fish mercury advisories for the Delta region.
- Expansion of the methylmercury source analysis (Chapter 6) and methylmercury allocation scheme (Chapter 8) to include methylmercury inputs to the portion of the Yolo Bypass that is north of the legal Delta using methods evaluated and found acceptable by the scientific peer reviewers. About 72% of the 73,300-acre Yolo Bypass is within the legal Delta boundary. Previous analyses indicated that the Yolo Bypass is a substantial source of methylmercury to the Delta, such that it makes sense to expand the methylmercury allocation scheme for the legal Delta to include the northern Yolo Bypass. Sacramento and Feather Rivers (via Fremont and Sacramento Weirs), Cache Creek, Willow Slough, and the Knights Landing Ridge Cut from the Colusa Basin all drain directly to the Yolo Bypass north of the legal Delta. Sources within the northern Yolo Bypass include wetlands and open water habitats, two WWTP discharges, agricultural lands, and a small amount of urbanized land. The 2006 draft TMDL Report included methylmercury allocations for sources within 30 miles of the legal Delta boundary; this revised report only includes allocations for dischargers within the legal Delta and the Yolo Bypass.
- Additional explanation of, and calculations for, the proposed methylmercury allocations to more directly address expected increases in source loading from predicted population growth and wetland restoration efforts.
- Changes to the methylmercury allocation strategy such that point and nonpoint sources with load-based allocations do not also have concentration allocations; this allows for a greater range of implementation options.
- Re-evaluation of the wetland and open-water methylmercury contributions (Chapter 6) using 2006 National Wetlands Inventory (NWI) wetland and open water acreages for the Delta/Yolo Bypass rather than the 1997 NWI acreages.
- Minor changes to methylmercury, total mercury and TSS load calculations (Chapters 6 and 7) based on additional quality assurance review of the concentration data and their use in regression-based load analyses.

- Minor textual changes throughout the report to clarify concepts and correct typographical errors identified in the June 2006 report.
- Expansion and re-location of the “Public Outreach” chapter (Chapter 9 in the June 2006 TMDL report) to the draft Basin Plan Amendment staff report (Chapter 8, “Public Participation & Agency Consultation”).

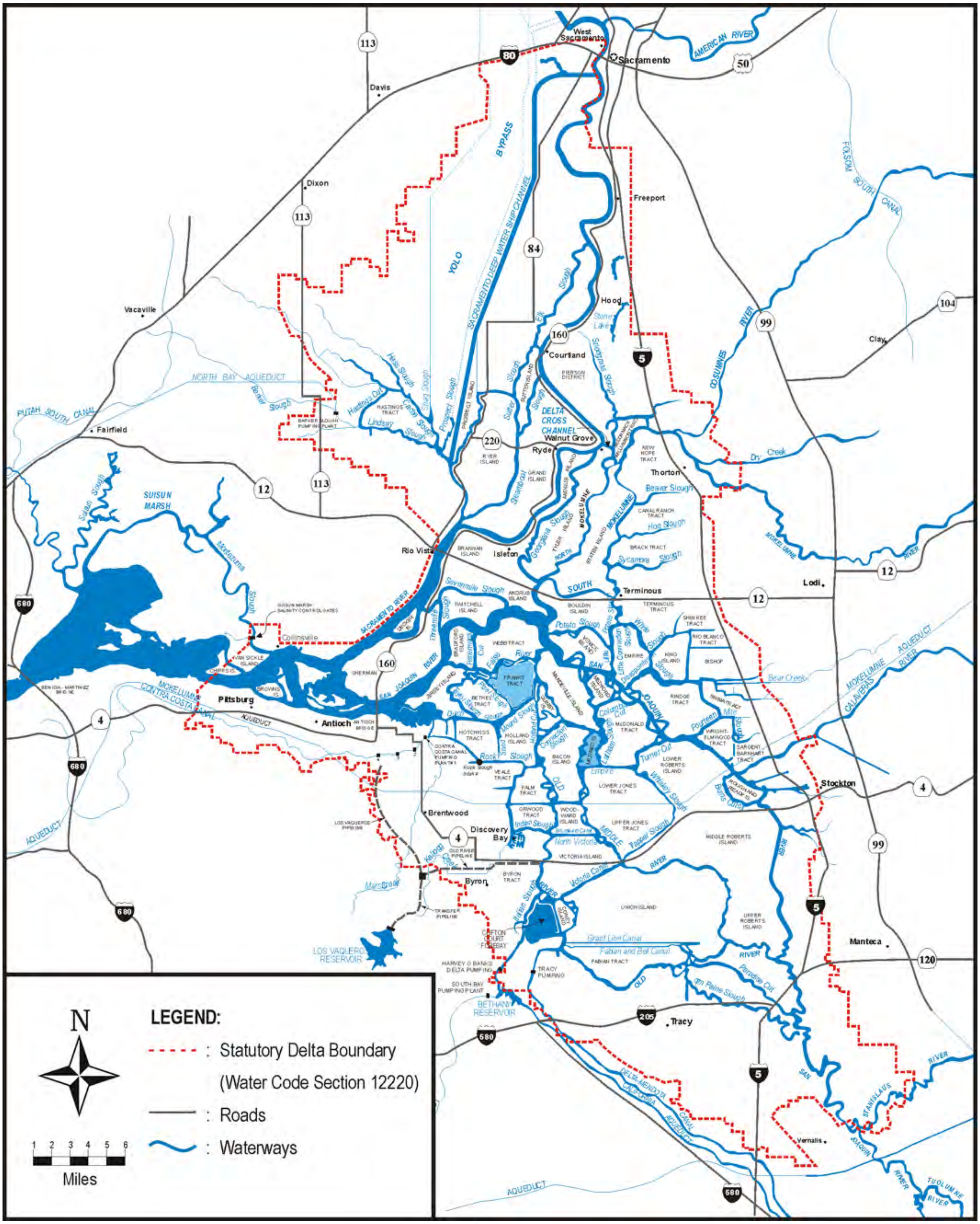

Figure 1.1: The Sacramento-San Joaquin Delta [DWR, 1995].
The dotted red line outlines the statutory boundary of the Delta.

2 PROBLEM STATEMENT

The Central Valley Water Board determined that the Delta is impaired by mercury. Fish-tissue data collected since 1970 in the Delta indicate that mercury levels exceed numeric criteria established for the protection of human and wildlife health. This Problem Statement presents information in four sections:

1. Regulatory Background and TMDL Timeline
2. Delta Characteristics and TMDL Scope
3. Mercury Effects & Sources
4. Beneficial Uses, Applicable Standards & Extent of Impairment

2.1 Regulatory Background & TMDL Timeline

2.1.1 Clean Water Act 303(d) Listing and Total Maximum Daily Load Development

Section 303(d) of the Federal Clean Water Act requires States to:

- Identify waters not attaining water quality standards (referred to as the "303(d) list").
- Set priorities for addressing the identified pollution problems.
- Establish a "Total Maximum Daily Load" for each identified water body and pollutant to attain water quality standards.

In 1990 the State Water Resources Control Board (State Water Board) adopted the 303(d) List that identified Delta waterways as impaired for mercury because of the presence of a fish consumption advisory (SWRCB-DWQ, 1990). The 1998 303(d) List identified the TMDL control program for mercury in the Delta as a high priority (SWRCB-DWQ, 2003).

A TMDL represents the maximum load (usually expressed as a rate, such as kilograms per day [kg/day] or other appropriate measure) of a pollutant that a water body can receive and still meet water quality objectives. A TMDL describes the reductions needed to meet water quality objectives and allocates those reductions among the sources in the watershed. Water bodies on the 303(d) List are not expected to meet water quality objectives even if point source dischargers comply with their current discharge permit requirements. TMDLs must include the following elements: description of the problem (Chapter 2), numerical water quality target (Chapter 4), analysis of current loads (Chapters 6 and 7), and load reductions needed to eliminate impairments (Chapter 8).

2.1.2 Porter-Cologne Basin Plan Amendment Process

The State of California Porter-Cologne Water Quality Control Act (Section 13240) requires the Central Valley Water Board to develop a water quality control plan for each water body in the Central Valley that does not meet its designated beneficial uses. The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (the Basin Plan) is the legal document that describes the beneficial uses of all water bodies in these basins, water quality objectives to protect them, and, if the objectives are not being met, an implementation program to correct the impairment (CVRWQCB, 1998). The water quality management strategy for mercury in the Delta includes:

- TMDL Development: involves the technical analysis of methyl and total mercury sources, fate and transport of each, development of proposed mercury fish tissue objectives, and a description of the amount of source reduction necessary to attain the proposed objectives.
- Basin Planning: focuses on the development of Basin Plan amendments and a staff report for Central Valley Water Board consideration. The draft Basin Plan amendments propose site-specific fish tissue objectives for the Delta and an implementation plan to achieve the objectives. The draft Basin Plan Amendment staff report includes information and analyses required to comply with the California Environmental Quality Act (CEQA). The Basin Planning process satisfies State Water Board regulations for the implementation of CEQA.[2]
- Implementation: focuses on the establishment of a framework that ensures that appropriate practices or technologies are implemented (§13241 and §13242 of the Porter-Cologne Water Quality Act), including those elements necessary to meet Federal TMDL requirements (CWA Section 303(d)).

The proposed Basin Plan amendments are legally enforceable once they have been adopted by the Central Valley and State Water Boards and approved by the Office of Administrative Law and the USEPA. Central Valley Water Board staff solicited public participation and scientific review throughout the TMDL development and implementation planning phases. Chapter 8 in the draft Basin Plan Amendment staff report describes the extensive public participation, scientific peer review, and agency consultation that have taken place to date. Also, the Basin Plan amendments will be adopted and approved in a public forum.

2.1.3 Timeline and Process for the Delta Mercury Management Strategy

The Delta methylmercury TMDL and Basin Planning processes began with the development of a draft technical mercury TMDL report, which was submitted to the USEPA in August 2005 and posted on the Central Valley Water Board website for public review. The June 2006 TMDL Report incorporated additional information from ongoing sampling and analyses and public input received on the August 2005 draft TMDL report. This draft TMDL report addresses scientific peer review comments and considers Central Valley Water Board member comments and questions voiced during the March 2007 workshop, additional input from agencies and other stakeholders, and supplementary evaluations to support the Basin Planning effort described in the draft Basin Plan Amendment staff report. Table 8.1 in the draft Basin Plan Amendment staff report provides a detailed description of the CEQA scoping, Board, and public workshops and other stakeholder meetings that have taken place to date. After staff has addressed any public comments on the draft TMDL and Basin Plan Amendment staff reports, the final draft Basin

[2] The Secretary of Resources has certified the planning process for Basin Plans as a regulatory program pursuant to PRC § 21080.5 and CEQA Guidelines §15251(g). This certification means basin planning is exempt from CEQA provisions that relate to preparing Environmental Impact Reports and Negative Declarations. The Basin Plan Staff Report satisfies the requirements of State Board Regulations for Implementation of CEQA, Exempt Regulatory Programs, which are found in the California Code of Regulations, Title 23, Division 3, Chapter 27, Article 6, beginning with Section 3775.

Plan Amendment staff report will be presented to the Central Valley Water Board for their consideration later in 2008.

2.1.4 Units and Terms Used in this Report

This report uses the term “total mercury” (TotHg) to indicate the sum of all forms of mercury (Hg) in water: physical states (e.g., dissolved, colloidal or particulate bound), chemical states (e.g., elemental, mercurous ion, or mercuric ion), organic compounds (e.g., monomethylmercury), and inorganic compounds (e.g., cinnabar). Monomethylmercury is the predominant form of organic mercury present in biological systems and will be noted in this report as “methylmercury” (MeHg). Because methylmercury typically composes only a small portion of total mercury in ambient water,[3] the phrases “inorganic mercury” and “total mercury” are sometimes used synonymously.

Concentrations of methyl and total mercury in water (also referred to as “aqueous” methyl and total mercury) are reported in units of nanograms per liter (ng/l). Aqueous methylmercury concentrations are rounded to three decimal places and total mercury concentrations are rounded to two decimal places. Concentrations of suspended sediment are analyzed as total suspended solids (TSS) and use units of milligrams per liter (mg/l) rounded to one decimal place. In Chapter 7 (Source Assessment – Total Mercury & Suspended Sediment), the concentration of total mercury in suspended sediment is calculated as the ratio of concentrations of mercury to suspended sediments (TotHg:TSS). Units for the concentration of mercury in suspended sediment are part per million (ppm; equivalent to ng/mg or mg/kg), dry weight. Mercury levels in sediment and soil are also presented as part per million, dry weight. The units for loads of methylmercury and total mercury are grams per year (g/yr) and kilograms per year (kg/yr), respectively. Sediment loads are given in terms of millions of kilograms per year (kg/yr x 10^6 or Mkg/yr). Water flow is presented in units of acre-feet per year or million acre-feet per year (M acre-ft) for annual rates, cubic feet per second (cfs) for instantaneous flow measurements, and million gallons per day (mgd) for treatment plants. All load calculations were typically rounded to two significant figures with calculations completed prior to rounding. For this draft report, additional significant figures occasionally were included to improve the reader’s ease in verifying calculations.

Concentrations of mercury in fish tissue are reported as milligrams per kilogram (mg/kg), wet weight basis, rounded to two decimal places. Mercury is typically analyzed as “total mercury” in fish because of the additional cost required for methylmercury analysis. However, mercury exists almost entirely in the methylated form in small and top trophic level[4] fish (Nichols *et al*., 1999; Becker and Bigham, 1995; Slotton *et al.*, 2004). Therefore, even though all the fish

---

[3] For example, a comparison of average annual methylmercury and total mercury loads from tributary watersheds to the Delta (Tables 6.2 and 7.1) indicates that methylmercury loading comprises only about 2% of all total mercury loading from the tributaries.

[4] Trophic levels are numerical descriptions of an aquatic food web. The USEPA’s 1997 Mercury Study Report to Congress used the following criteria to designate trophic levels based on an organism’s feeding habits:

Trophic level 1: Phytoplankton and bacteria.
Trophic level 2: Zooplankton, benthic invertebrates and some small fish.
Trophic level 3: Organisms that consume zooplankton, benthic invertebrates, and other TL2 organisms.
Trophic level 4: Organisms that consume TL3 organisms.

mercury data presented in the report were generated by laboratory analyses for total mercury, the data are described as “methylmercury concentrations in fish”.

Rates of fish consumption are given as grams of fish eaten per day (g/day) or meals per week. One adult human meal is assumed to be eight uncooked ounces (227 grams). Humans and wildlife species consume fish and other aquatic organisms from various size ranges and trophic levels. Safe fish tissue levels are identified in Chapter 4 for different trophic level and size classifications. These classifications are termed “trophic level food groups”.

For this report, methylmercury fish tissue concentrations in trophic level food groups are recommended as the TMDL water quality **targets**. The tissue targets will be proposed as options for the Central Valley Water Board to consider when adopting fish tissue objectives. The term **implementation goal** in this report refers to methylmercury concentrations in standard 350-mm largemouth bass and unfiltered water, which are correlated to the targets. The implementation goal for methylmercury in unfiltered ambient water is Central Valley Water Board staff’s best estimate of the annual average methylmercury concentration in water needed to achieve the fish tissue targets. The “implementation goal” for methylmercury in ambient water is used to determine the methylmercury source load reductions necessary to meet the targets. The methylmercury water goal is not being proposed as a water quality objective.

2.2 Delta Characteristics and TMDL Scope

2.2.1 Delta Geography

The Sacramento-San Joaquin Delta, along with the San Francisco Bay, forms the largest estuary on the west coast of North America. The Delta encompasses a maze of over 1,100 miles of river channels surrounding about 738,000 acres (1,153 square miles) of diked islands and tracts in Alameda, Contra Costa, Sacramento, San Joaquin, Solano and Yolo counties (Figure 1.1 and Figure A.1 in Appendix A). Many of the Delta waterways follow natural courses while others have been constructed to provide deep-water navigation channels, to improve water circulation, or to obtain material for levee construction (DWR, 1995). The legal boundary of the Delta is defined in California Water Code Section 12220. Appendix A illustrates the more than 100 named waterways addressed by this TMDL.

The Delta and its source watersheds comprise nearly 40% of the landmass of the State of California (Table 2.1 and Figure 2.1). The Sacramento, San Joaquin, Mokelumne, Cosumnes, and Calaveras rivers all flow into the Delta, carrying approximately 47% of the State’s total runoff (DWR, 2005). Major reservoirs and lakes in the Sacramento Basin include Shasta, Whiskeytown, Oroville, Englebright, Camp Far West, Folsom, and Black Butte, Indian Valley, Clear Lake and Lake Berryessa. Major reservoirs and lakes in the San Joaquin Basin include Camanche, New Hogan, New Melones/Tulloch, Don Pedro, McClure, Burns, Bear, Owens, Eastman, Hensley, Millerton and Marsh Creek.

The legal Delta encompasses the southern two thirds of the Yolo Bypass, a 73,300-acre floodplain on the west side of the lower Sacramento River. The Fremont and Sacramento Weirs route floodwaters from the Sacramento River and its associated tributary watersheds around the

Sacramento urban area to the Yolo Bypass. Cache and Putah Creeks, Willow Slough, and the Knights Landing Ridge Cut from the Colusa Basin all drain directly to the Yolo Bypass.

The Sacramento River contributes an average annual water volume of 18.3 million acre-feet and the Yolo Bypass and the San Joaquin River contribute an average of 5.8 million acre-feet. Diversions in the Delta include the State Water Project (Banks Pumping Plant and the North Bay Aqueduct), Central Valley Project (Tracy Pumping Plant), and Contra Costa Water District, which withdraw average annual water volumes of about 3.7 million, 2.5 million, and 126 thousand acre-feet, respectively (DWR, 2005). During a typical water year,[5] the Delta receives runoff only from the Sacramento and San Joaquin Basins in the Central Valley (Figure 2.1). During infrequent flood events, the Tulare Basin in the southern Central Valley is connected to the San Joaquin River system.

The mean annual precipitation in the City of Stockton in the eastern Delta is approximately 14 inches, with the majority of rain falling between November and March. Temperatures at Stockton typically average 62 degrees Fahrenheit (^{o}F), with summer highs exceeding 90 ^{o}F and winter lows dropping below 40 ^{o}F.

The Delta had a population of 410,000 people in 1990 (DWR, 1995). As of the 2000 Census, about 462,000 people resided in the Delta region (DWR, 2005). Rapid growth is occurring in urban areas in and surrounding the Delta, especially in Elk Grove (27% growth per year – the highest growth rate in California), Tracy (5.9% per year), Brentwood (12.3% per year), and Rio Vista (11.1% per year).

Agriculture and recreation are the two primary businesses in the Delta. The Delta also provides habitat for over five hundred species of wildlife (DWR, 1995; Herbold *et al.*, 1992). The Delta is the major source of fresh water to San Francisco Bay and supplies drinking water for over two-thirds of the State's population (over 23 million people) and irrigation water for more than seven million acres of farmland statewide (DWR, 2005). Table 2.2 lists additional features of the Delta.

Space intentionally left blank.

[5] A "water year" (WY) is defined as the period between 1 October and 30 September of the following year; for example, WY2001 is the period between 1 October 2000 and 30 September 2001. Water year types in California are classified according to the natural water production of the major basins. See Appendix E for more information about water year classifications.

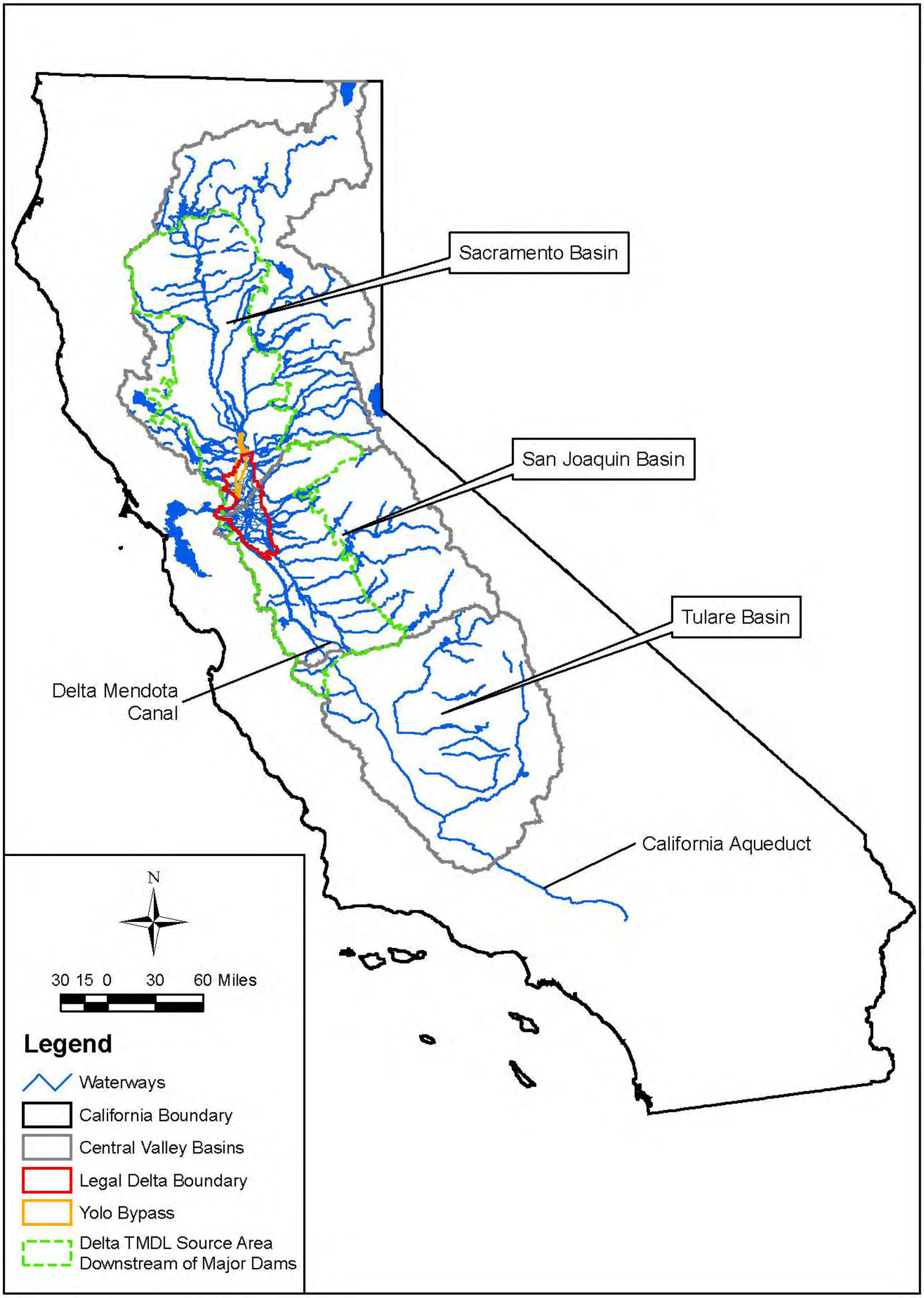

Figure 2.1: The Central Valley

Table 2.1: Spatial Perspective of the Delta and Its Source Regions

Region	Acreage	Square Miles	% of California	% of Central Valley
California	101,445,246	158,508	---	---
Central Valley	37,982,554	59,348	37%	---
Delta (legal boundary)	737,630	1,153	1%	1.9%
Delta Watershed (Statutory Delta & all tributary watersheds that ultimately drain directly to the Delta)	27,226,796	42,542	27%	72%
Delta Watershed Area Downstream of Major Dams	12,469,054	19,483	12%	33%
Sacramento River Watershed	17,410,314	27,204	17%	46%
San Joaquin River Watershed	9,801,103	15,314	10%	26%

Table 2.2: Key Delta Features (DWR, 1995 and 2005)

Population:	410,000 (1990), 462,000 (2000)	Area (acres):	Agriculture: 538,000 Cities & towns: 64,000 Water surface: 61,000 Undeveloped: 75,000 *Total: 738,000*
Incorporated cities entirely within the Delta:	Antioch, Brentwood, Isleton, Pittsburg, Tracy		
Major cities partly within the Delta:	Sacramento, Stockton, West Sacramento		
# of unincorporated towns and villages:	14	Total length of all leveed channels:	1,100 miles (1987)
Main crops:	Alfalfa asparagus corn fruit grain & hay grapes pasture safflower sugar beets tomatoes	Diversions from the Delta:	Central Valley Project State Water Project Contra Costa Canal City of Vallejo Western Delta Industry 1,800+ Agricultural diversions
		Rivers flowing into the Delta:	Calaveras Cosumnes Sacramento San Joaquin Mokelumne

Fish and wildlife:		# of Species [a]	# of Federal & State Species of Concern [a]	# of Non-Native Species [b]
	Birds:	230	10	3
	Mammals:	45	9	7
	Fish:	52	8	30
	Reptiles & amphibians:	25	6	1
	Flowering plants:	150	54	70
	Invertebrates:	na	21	13
	Major anadromous fish: American shad, salmon, steelhead trout, striped bass, sturgeon			

(a) Endangered, threatened, rare, and candidate species per the Federal listing effective January 31, 1992, and the State listing effective April 9, 1992, as cited in the Sacramento – San Joaquin Delta Atlas (DWR, 1995).

(b) Introduced species in the Sacramento – San Joaquin Delta, as cited in the Sacramento – San Joaquin Delta Atlas (DWR, 1995).

2.2.2 TMDL Scope & Delta Subareas

This TMDL addresses fish mercury impairment in all waterways within the legal Delta, except the westernmost portion of the Delta near Chipps Island that falls within the jurisdiction of the San Francisco Bay Regional Water Quality Control Board (Figure 2.2; see Appendix A for a list of named waterways). Tributaries are considered to be nonpoint sources to the Delta and are evaluated at or near the locations where they cross the statutory Delta boundary. Assessment of point and nonpoint sources that contribute to tributary discharges to the Delta is ongoing and will be described in reports for future mercury TMDL programs for those watersheds and implementation activities for the Delta methylmercury TMDL.

The methylmercury source analysis and linkage analysis for the Delta TMDL divide the Delta into eight regions based on the hydrologic characteristics and mixing of the source waters (Figure 2.2). A hydrology-based methylmercury TMDL is proposed in this report as it more accurately reflects the concentrations and sources of methylmercury and the extent of fish impairment. As described in Chapter 8 (Allocations), essentially a separate methylmercury allocation scheme is developed for each subarea because the methylmercury sources and level of fish impairment in each subarea are different. The following paragraphs describe the delineation of the hydrologic subareas.

<u>Sacramento River</u>: This subarea is dominated by Sacramento River flows. It is bound to the east by the legal Delta boundary and to the west by the eastern levee of the Sacramento Deep Water Ship Channel. Sacramento River flows influence the Upper and Lower Mokelumne River in the Delta because of diversions by the Delta Cross Channel near Walnut Grove (Figure A.1 in Appendix A). The Delta Cross Channel controls diversions of fresh water from the Sacramento River to Snodgrass Slough and the Mokelumne River to combat salt-water intrusion in the Delta, to dilute local pollution, and to more efficiently supply the Federal Central Valley Project and State Water Project pumps in the southern Delta.

Although drawn as a defined line, the Sacramento River subarea's boundary with the South Yolo Bypass, Central Delta, and West Delta subareas is defined by a gradient in water quality characteristics that varies depending on the tidal cycle, magnitude of wet weather flows, diversions by within-Delta control structures, and releases from reservoirs in the upstream watersheds.

<u>Yolo Bypass - North & South</u>: The Yolo Bypass is a 73,300-acre floodplain on the west side of the lower Sacramento River (see Section E.2.2 and Figure E.2 in Appendix E for the floodplain boundary definition). The Fremont and Sacramento Weirs route floodwaters to the Yolo Bypass from the Sacramento and Feather Rivers and their associated tributary watersheds. Cache and Putah Creeks, Willow Slough, and the Knights Landing Ridge Cut from the Colusa Basin all drain directly to the Yolo Bypass. The legal Delta encompasses only the southern two thirds of the Yolo Bypass. The "Yolo Bypass – North" subarea is defined by Fremont Weir to the north and Lisbon Weir to the south and includes areas within and north of the legal Delta boundary. The "Yolo Bypass – South" subarea is defined by Lisbon Weir to the north and the southern end of Cache Slough to the south. Lisbon Weir (Figure E.2) limits the range of tidal fluctuation upstream in the Yolo Bypass.

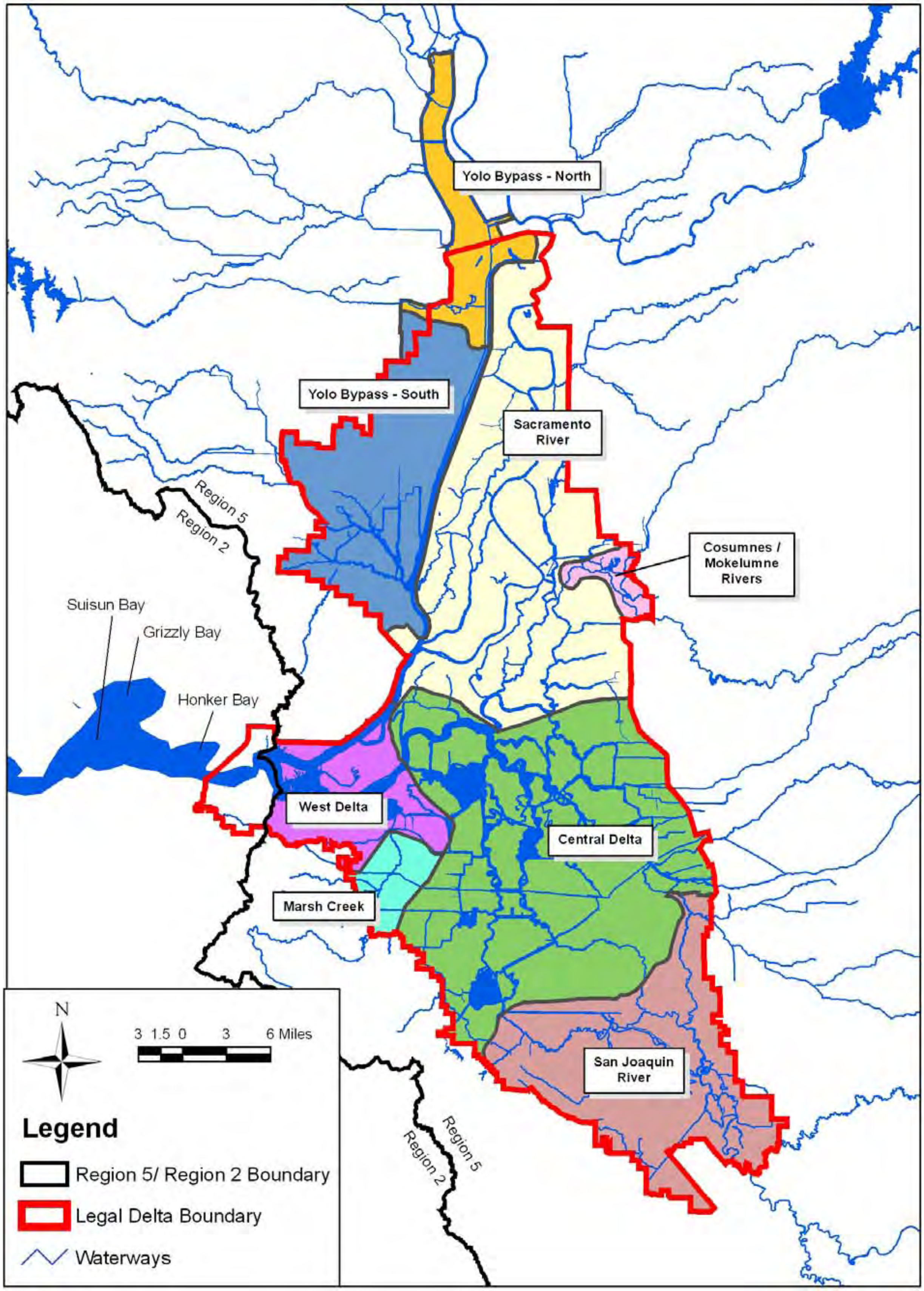

Figure 2.2: Hydrology-Based Delineation of Subareas within the Legal Delta and Yolo Bypass

Cosumnes/Mokelumne Rivers: This subarea includes the lower Cosumnes and Mokelumne Rivers and is defined by the legal Delta boundary to the east and the Delta Cross Channel confluence with the Mokelumne to the west.

San Joaquin River: This subarea is defined by the legal Delta boundary to the east and south, and Grantline Canal and the beginning of the Stockton Deep Water Channel to the north. At present, the San Joaquin River is almost entirely diverted out of the Delta by way of Old River and Grantline Canal for export south of the Delta via the State and Federal pumping facilities near Tracy.

Marsh Creek: This subarea is defined by the portion of the Marsh Creek watershed within the legal Delta boundary that is upstream of tidal effects.

West Delta: The West Delta subarea encompasses the confluence of the Sacramento and San Joaquin Rivers, which transport water from the Central Valley to the San Francisco Bay. The western border of the West Delta subarea is defined by the jurisdictional boundary between the Central Valley Regional Water Quality Control Board (Region 5) and the San Francisco Water Board (Region 2) (Figure 2.2). Water quality characteristics are determined by the tidal cycle, magnitude of wet weather flows, controlled flow diversions by within-Delta structures, and releases from reservoirs in the upstream watersheds.

Central Delta: The Central Delta includes a myriad of natural and constructed channels that transport water from the upper watersheds to San Francisco Bay to the west and the State and Federal pumps to the southwest. The Central Delta tends to be most influenced by waters from the Sacramento River.

2.3 Mercury Effects & Sources

2.3.1 Mercury Chemistry and Accumulation in Biota

Mercury (Hg) can exist in various forms in the environment. Physically, mercury can exist in water in a dissolved, colloidal or particulate bound state. Chemically, mercury can exist in three oxidation states: elemental (Hg^o), mercurous ion (monovalent, Hg^+), or mercuric ion (divalent, Hg^{+2}). Ionic mercury can react with other chemicals to form both organic and inorganic compounds, such as cinnabar (HgS), and can be converted by sulfate reducing bacteria to more toxic organic compounds, such as monomethylmercury (CH_3Hg) or dimethylmercury ($(CH_3)_2Hg$). Important factors controlling the conversion rate of inorganic to organic mercury include temperature, percent organic matter, redox potential, salinity, pH, and mercury concentration. Monomethylmercury is the predominant form of organic mercury present in biological systems and will be noted in this report as methylmercury or “MeHg”. Because dimethylmercury is an unstable compound that dissociates to monomethylmercury at neutral or acid pH, it is not a concern in freshwater systems (USEPA, 1997a). Chapter 3 provides more information about potentially controllable methylation processes in the Delta region.

Both inorganic and organic mercury can be taken up by aquatic organisms from water, sediments and food. Low trophic level species such as phytoplankton obtain all their mercury directly from the water. *Bioconcentration* describes the net accumulation of mercury directly from water. The *bioconcentration factor* is the ratio of mercury concentration in an organism to mercury concentration in water. Mercury may also accumulate in aquatic organisms from consumption of mercury-contaminated prey (USEPA, 1997b). Mercury *bioaccumulates* in organisms when rates of uptake are greater than rates of elimination.

Repeated consumption and accumulation of mercury from contaminated food sources results in tissue concentrations of mercury that are higher in each successive level of the food chain. This process is termed *biomagnification*. Methylmercury accumulates within organisms more than inorganic mercury because inorganic mercury is less well absorbed and/or more readily eliminated than methylmercury. The proportion of mercury that exists as the methylated form generally increases with the level of the food chain, typically greater than 90% in top trophic level fish (Nichols *et al.*, 1999; Becker and Bigham, 1995).

Consumption of contaminated, high trophic level fish is the primary route of methylmercury exposure. For example, the aquatic food web provides more than 95% of humans' intake of methylmercury (USEPA, 1997a). Wildlife species of potential concern that consume fish and other aquatic organisms from the Delta include piscivorous fish, herons, egrets, mergansers, grebes, bald eagle, kingfisher, peregrine falcon, osprey, mink, raccoon and river otter.

2.3.2 Toxicity of Mercury

Mercury is a potent neurotoxicant. Methylmercury is the most toxic form of this metal. Methylmercury exposure causes multiple effects, including tingling or loss of tactile sensation, loss of muscle control, blindness, paralysis, birth defects and death. Adverse neurological effects in children appear at dose levels five to ten times lower than associated with toxicity in adults (NRC, 2000). Children may be exposed to methylmercury during fetal development, by eating fish, or through both modes. Effects of methylmercury are dose dependent.

Wildlife species may also experience neurological, reproductive or other detrimental effects from mercury exposure. Behavioral effects such as impaired learning, reduced social behavior and impaired physical abilities have been observed in mice, otter, mink and macaques exposed to methylmercury (Wolfe *et al.*, 1998). Reproductive impairment following mercury exposure has been observed in multiple species, including common loons and western grebe (Wolfe *et al.*, 1998), walleye (Whitney, 1991 in Huber, 1997), mink (Dansereau *et al.*, 1999) and fish (Huber, 1997; Wiener and Spry, 1996).

2.3.3 Mercury Sources & Historic Mining Activities

Identified sources of methyl and total mercury in the Delta and in tributary watersheds include geothermal springs, methylmercury flux from sediments in wetlands and open water habitats, municipal and industrial dischargers, agricultural drainage, urban runoff, atmospheric deposition, and erosion of naturally mercury-enriched soils and excavated overburden and tailings from historic mining operations. Although none are present within the legal Delta, historic mercury and gold mining sites – along with their associated contaminated waterways – may contribute a substantial portion of the total mercury in the tributary discharges to the Delta. Chapters 6 and 7 provide a detailed assessment of the within-Delta sources of methyl and total mercury.

As noted in source analyses in Chapters 6 and 7, tributary inputs to the Delta are the largest sources of methyl and total mercury. These tributaries drain many of the major mercury mining districts in the Coast Range and the placer gold mining fields in the Sierra Nevada Mountains. The Coast Range is a region naturally enriched in mercury. Active geothermal vents and hot springs deposit mercury, sulfur, and other minerals at or near the earth's surface. Most of the mercury deposits in California occur within a portion of the Coast Range geomorphic province extending from Clear Lake in Lake County in the north to Santa Barbara County in the south. Approximately 90% of the mercury (roughly 104 million kilograms) used in the United States between 1846 and 1980 was mined in the Coast Range of California (Churchill, 2000). Much of the mining and extraction occurred prior to 1890 when mercury processing was crude and inefficient. The ore was processed at the mine sites, with about 35 million kilograms of mercury lost at the mine sites. As a result, high levels of mercury are present in sediment and fish tissue in Coast Range water bodies. Fish advisories have been posted for Clear Lake, Cache Creek, Lake Berryessa and Black Butte Reservoir (Stratton *et al.*, 1987; Brodberg and Klasing, 2003; Gassel *et al*., 2005). Mercury mine waste enters the Delta from mine-impacted Coast Range creeks such as Cache, Putah and Marsh Creeks.

Approximately 10 million kilograms of Coast Range mercury were transported across the valley and used as an amalgam in placer and lode gold mining in the Sierra Nevada Mountains between 1850 and 1890 (Churchill, 2000). Approximately six million kilograms of mercury were lost in Sierra Nevada rivers and streams during gold mining operations. Principal gold mining areas were in the Yuba River and Bear River (tributaries to the Sacramento River via the Feather River), the Cosumnes River (a tributary to the Mokelumne River), and the Stanislaus, Tuolumne and Merced Rivers (tributaries to the San Joaquin River). Elevated mercury concentrations are present in fish in all these Sierra Nevada waterways. Floured[6] elemental mercury enters the Delta from the Sacramento, Mokelumne and San Joaquin Rivers.

Evaluation of legacy mine sites, associated contaminated waterway reaches, and other methyl and total mercury sources that contribute to tributary inputs to the Delta is ongoing. More detailed source analyses for the tributary watersheds will be conducted by future mercury TMDL programs for those watersheds and by proposed implementation actions for the Delta mercury control program (see Chapter 4 in the draft Basin Plan Amendment staff report).

2.4 Beneficial Uses, Applicable Standards & Extent of Impairment

2.4.1 Sacramento-San Joaquin Delta Estuary Beneficial Uses

The Federal Clean Water Act and the State Water Code (Porter-Cologne Water Quality Act) require the State to identify and protect the beneficial uses of its waters. Table 2.3 lists the existing beneficial uses of the Delta. Human consumption of fish and shellfish (currently assumed under REC-1) and wildlife habitat (WILD) are impaired because of elevated mercury

[6] Flouring is the division of mercury into extremely small globules, which gives it a white, flour-like appearance. If the floured mercury has surface impurities such as oil, grease, clay or iron and base metal sulfides, it will not coalesce into larger drops or form an amalgam with gold (Beard, 1987). Mercury was used for gold recovery throughout the Sierra Nevada. Floured mercury was formed by the pounding of boulders and gravels over liquid mercury in hydraulic mining-related sluice boxes (Hunerlach *et al.*, 1999), as well by intense grinding in the hardrock milling systems, and was transported downstream with tailings.

concentrations in fish throughout the Delta. Municipal and domestic supply (MUN) is impaired because of elevated mercury concentrations in water in the Yolo Bypass. The Basin Plan does not include a commercial and sport fishing (COMM) designation for the Delta, which includes uses of water for commercial or recreational collection of fish, shellfish, or other organisms intended for human consumption or bait purposes. However, as described in Appendix C, commercial and sport fishing take place in the Delta. Some sport and commercial species (e.g., striped bass and largemouth bass) are impaired by mercury, while others (e.g., salmon and clams) are not. The draft Basin Plan Amendment staff report considers adoption of a COMM beneficial use for the Delta.

Table 2.3: Existing Beneficial Uses of the Delta [a]

Beneficial Use	Status
Municipal and domestic supply (MUN)	Existing [b]
Agriculture – irrigation and stock watering (AGR)	Existing
Industry – process (PROC) and service supply (IND)	Existing
Contact recreation (REC-1) [c]	Existing [b]
Non-contact recreation (REC-2) [c]	Existing
Freshwater habitat (warm and cold water species)	Existing
Spawning, reproduction and/or early development of fish (SPWN) (warm water species)	Existing
Wildlife habitat (WILD)	Existing [b]
Migration of aquatic organisms (MIGR) (warm and cold water species)	Existing
Navigation (NAV)	Existing

(a) This table lists the beneficial uses designated for the Delta in Table II-1 of the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (CVRWQCB, 1998).

(b) These are beneficial uses impaired by mercury in the Delta.

(c) REC-1 includes recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing and fishing. REC-2 includes recreational activities involving proximity to water, but where there is generally no body contact with water, nor any likelihood of ingestion of water. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, hunting and sightseeing.

2.4.2 Applicable Standards & Extent of Impairment

The narrative water quality objective for toxicity in the Basin Plan states, "All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life." The narrative toxicity objective further says that "The Regional Water Board will also consider … numerical criteria and guidelines for toxic substances developed by the State Water Board, the California Office of Environmental Health Hazard Assessment, the California Department of Health Services, the U.S. Food and Drug Administration, the National Academy of Sciences, the USEPA, and other appropriate organizations to evaluate compliance with this objective" (CVRWQCB, 1998). Four potential criteria were evaluated to determine whether the Delta was in compliance with the narrative objective. They are the USEPA and USFWS fish tissue criteria for protection of human and wildlife, the USEPA aqueous methylmercury criterion for drinking water, the United Nations aqueous total mercury guidance level to protect livestock, and the California Toxic Rule (CTR) aqueous total mercury criterion for protection of human and wildlife health. Each is reviewed below and a determination made as to whether the recommended criteria or objective is met in the Delta or not.

2.4.2.1 Fish Tissue Criteria

In 1971, a human health advisory was issued for the Sacramento-San Joaquin Delta advising pregnant women and children not to consume striped bass. In 1994, an interim advisory was issued by the California Office of Environmental Health Hazard Assessment (OEHHA) for San Francisco Bay and Delta recommending no consumption of large striped bass and shark because of elevated concentrations of mercury and polychlorinated biphenyls (OEHHA, 1994). Additional monitoring indicates that several more species, including largemouth bass and white catfish (two commonly-caught local sport fish), also have elevated concentrations of mercury in their tissue (Davis *et al.*, 2003; Slotton *et al.*, 2003; LWA, 2003; SWRCB-DWQ, 2002).

In 2007, OEHHA issued drafts of safe eating guidelines for the South Delta and the lower Cosumnes River, lower Mokelumne River, and San Joaquin River from Port of Stockton to Friant Dam[7] (OEHHA, 2006 and 2007). The South Delta guidelines encompass much of the Central Delta, West Delta, and San Joaquin River subareas of the TMDL. All of the new guidelines continue restrictions on consumption of striped bass. In addition, the new guidelines provide consumption advice for other sport fish, crayfish, and clams. OEHHA suggests that pregnant and nursing women should limit consumption of largemouth bass, carp, and crappie to 8 ounces uncooked fish per week in the South Delta and should avoid largemouth bass from the San Joaquin and lower Cosumnes Rivers. OEHHA anticipates releasing safe eating guidelines in 2008 for the North Delta, which would cover the Sacramento River and rest of the Central Delta TMDL subareas.

The Delta was listed for mercury because of the 1971 and 1994 fish advisories and because some fish tissue concentrations exceeded the National Academy of Sciences (NAS) guidelines for protection of wildlife health. The NAS wildlife guideline is 0.5 mg/kg mercury in whole, freshwater fish (NAS, 1973). The USEPA has since published a recommended criterion for the protection of human health of 0.3 mg/kg mercury in fish tissue (USEPA, 2001). Similarly, the USFWS has provided guidance on safe methylmercury ingestion rates for sensitive wildlife species (USFWS, 2002, 2003 and 2004). The Delta TMDL cites the USEPA and USFWS recommended criteria for protection of human and wildlife health, as these are more protective.

Significant regional variations in fish tissue mercury concentrations are observed in the Delta. Elevated concentrations occur along the periphery of the Delta while lower body burdens are measured in the central Delta. A summary of fish tissue methylmercury concentrations by Delta subarea is provided in Chapter 4 (Tables 4.7 and 4.10) and Appendix C. Concentrations are greater than recommended as safe by the USEPA and USFWS at all locations except in the central Delta. Percent reductions in fish methylmercury levels ranging from 0% to 75% in the

[7] OEHHA's recent advisories are in the form of safe eating guidelines that indicate which fish species may be eaten safely as well as those that should be avoided or eaten less frequently.

peripheral Delta subareas will be needed to meet the numeric targets for wildlife and human health protection.

2.4.2.2 Aqueous Criteria & Guidance

The USEPA recommends a safe level of 70 ng/l methylmercury in drinking water to protect humans (USEPA, 1987). This level was released through USEPA's Integrated Risk Information System (IRIS) and was based on USEPA's recommended methylmercury reference dose for lifetime exposure. Methylmercury concentrations in the Delta typically range from 0.02 to 0.3 ng/l (Section 6.2.1). The maximum observed concentration in the Delta between March 2000 and April 2004 was 0.70 ng/l in Prospect Slough in March 2000 (Appendix L). The USEPA IRIS drinking water criterion is not expected to be exceeded in the Delta.

The United Nations recommends a guidance level of 10,000 ng/l unfiltered total mercury to protect livestock drinking water (Ayers and Westcot, 1985). Unfiltered mercury concentrations in the Delta typically range from 0.26 to 100 ng/l (Table 7.4 in Chapter 7). The maximum concentration ever observed in the Delta was 696 ng/l at Prospect Slough on January 10, 1995. The United Nations recommended livestock guidance level is not expected to be exceeded in the Delta.

The USEPA promulgated the CTR in April 2000 (USEPA, 2000b). The CTR mercury objective is 0.05 µg/L (50 ng/l) total recoverable mercury for freshwater sources of drinking water. The CTR criterion was developed to protect humans from exposure to mercury in drinking water and in contaminated fish. It is enforceable for all waters with a municipal and domestic water supply or aquatic beneficial use designation. This includes all subareas of the Delta. The CTR does not specify duration or frequency. The Central Valley Water Board has previously employed a 30-day-averaging period with an allowable exceedance frequency of once every three years.[8] The USFWS and U.S. National Marine Fisheries Service are concerned that the mercury objective in the CTR may not protect threatened and endangered species and requested that the USEPA reevaluate the criterion. The USEPA has not released a reevaluation. Therefore, the CTR objective of 50 ng/l is applicable to the Delta.

An evaluation of unfiltered total mercury concentrations in Delta water demonstrates that the CTR is not exceeded anywhere in the Delta except downstream of the Cache Creek Settling Basin in the Yolo Bypass and possibly in Putah Creek, Prospect Slough and Marsh Creek (Section 7.5). The exceedances downstream of Cache Creek may be addressed by the Cache Creek mercury control program (Cooke and Morris, 2005) adopted in October 2005 and proposed upgrades of the Cache Creek Settling Basin described in Chapter 4 of the draft Basin Plan Amendment staff report. Prospect Slough is downstream of Cache Creek and potential exceedances of the CTR could be corrected with decreases in mercury loads from Cache Creek and its Settling Basin. Putah and Marsh Creeks are both on the 303(d) list because of elevated mercury concentrations. Exceedance of the CTR downstream of these water bodies will be addressed by load reductions to be determined by their TMDLs. Chapters 7 and 8 will provide additional evaluations of total mercury loads from these watersheds and potential reduction strategies.

[8] Personal communication from P. Woods (USEPA Region 9) to J. Marshack (CVRWQCB), 4 December 2001.

2.4.2.3 San Francisco Bay Mercury TMDL's Allocation for Total Mercury in Central Valley Outflows

As a component of the mercury control program for the San Francisco Bay, San Francisco Water Board staff developed a target for San Francisco Bay sediment mercury concentration (particle-bound mercury mass divided by sediment mass) of 0.2 mg/kg and assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr at Mallard Island or a decrease of 110 kg/yr in mercury sources to the Delta (Johnson and Looker, 2004; SFBRWQCB, 2006). Compliance with the allocation can be assessed by one of two methods:

> "First, attainment may be demonstrated by documentation provided by the Central Valley Water Board that shows a net 110 kg/yr decrease in total mercury entering the Delta from within the Central Valley region. Alternatively, attainment of the load allocation may be demonstrated by multiplying the flow-weighted suspended sediment mercury concentration by the sediment load measured at the RMP Mallard Island monitoring station. If sediment load estimates are unavailable, the load shall be assumed to be 1,600 million kg of sediment per year. The mercury load fluxing past Mallard Island will be less than or equal to 330 kg/yr after attainment of the allocation." (Johnson and Looker, 2004, page 66)

Central Valley Water Board staff will recommend to the Central Valley Water Board that the 110 kg total mercury reduction be met by reductions in total mercury entering the Delta from within the Central Valley. Reduction efforts are recommended for the Cache Creek, Feather River, American River and Putah Creek watersheds because they export the largest volume of highly contaminated sediment (see Chapter 8 in this TMDL report and Chapter 4 in the draft Basin Plan Amendment staff report). Load calculation methods and strategies for reducing total mercury loading to San Francisco Bay are discussed more in Chapters 7 and 8 of this report.

Key Points

- The Federal Clean Water Act (CWA) requires States to identify water bodies that do not meet their designated beneficial uses and to develop programs to eliminate impairments. States refer to the control program as a Total Maximum Daily Load (TMDL) program. A TMDL is the total maximum daily load of a pollutant that a water body can assimilate and still attain beneficial uses.
- The State of California Porter-Cologne Water Quality Control Act requires the Central Valley Water Board to develop a water quality control plan for each water body in the Central Valley that does not meet its designated beneficial uses. The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (the Basin Plan) is the legal document that describes the beneficial uses of all water bodies in these basins, adopted water quality objectives to protect them, and, if the objectives are not being met, an implementation program to correct the impairment.
- This draft TMDL report addresses scientific peer review comments on the June 2006 draft TMDL report, Central Valley Water Board member comments and questions voiced during the March 2007 workshop, additional input from agencies and other stakeholders, and supplementary evaluations to support the Basin Planning effort described in the draft Basin Plan Amendment staff report. After staff has addressed any public comments on this draft TMDL and Basin Plan Amendment staff reports, the final draft Basin Plan Amendment staff report will be presented to the Central Valley Water Board for their consideration later in 2008.
- In 1990 the Central Valley Water Board identified the Delta as impaired by mercury because fish had elevated levels of mercury that posed a risk for human and wildlife consumers. In addition, the San Francisco Bay mercury control program identified Central Valley outflows via the Delta as one of the principal sources of total mercury to San Francisco Bay and assigned the Central Valley a load reduction of 110 kg/yr. Therefore, the final mercury TMDL control plan for the Delta must ensure protection of human and wildlife health in the Delta and meet the San Francisco Bay load allocation for the Central Valley.
- The scope of the Delta methylmercury TMDL includes all waterways within the legal Delta boundary and the Yolo Bypass north of the Delta. This TMDL addresses both methyl and total mercury. Reductions in methylmercury concentrations in ambient water are required to reduce methylmercury concentrations in fish. Reductions in total mercury loads are needed to maintain compliance with the USEPA's criterion of 50 ng/l; to prevent increases in total mercury discharges from causing increases in aqueous and fish methylmercury in the Delta, thereby worsening the impairment; and to meet the San Francisco Bay TMDL allocation to the Central Valley.
- Elevated fish mercury concentrations occur along the periphery of the Delta while lower body burdens are measured in the central Delta. Concentrations are greater than recommended as safe by the USEPA and USFWS at all locations except in the central Delta. Percent reductions in fish methylmercury levels ranging from 0% to 80% in the peripheral Delta subareas will be needed to meet the numeric targets for wildlife and human health protection.

3 POTENTIALLY CONTROLLABLE METHYLATION PROCESSES IN THE DELTA

The problem with mercury in the Delta's aquatic ecosystems can be defined as biotic exposure to methylmercury (Wiener *et al.*, 2003a). Therefore, decreasing biotic exposure to methylmercury is the ultimate goal of the Delta methylmercury TMDL and implementation program. Several published papers provide comprehensive reviews of the current knowledge of the methylmercury cycle (e.g., Wiener *et al.*, 2003a and 2003b; Tetra Tech, Inc., 2005a; LWA, 2002). This chapter focuses on the processes that are potentially controllable in the Delta. The concepts summarized in this chapter guided the development of the methylmercury TMDL for the Delta, particularly the linkage analyses (Chapter 5), methyl and total mercury source analyses (Chapters 6 and 7), and recommended methylmercury allocations and total mercury limits (Chapter 8). Data gaps and uncertainties associated with each factor are identified in this chapter and then addressed further by recommendations for source characterization and control studies in Chapter 4 of the draft Basin Plan Amendment staff report.

Methylmercury concentrations in aquatic ecosystems are the result of two competing processes: methylation and demethylation. Neither is well understood. Methylation is the addition of a methyl group (CH_3) to an inorganic mercury molecule (Hg^{+2}). Sulfate reducing bacteria are the primary agents responsible for the methylation of mercury in aquatic ecosystems (Compeau and Bartha, 1985; Gilmour *et al.* 1992). Small amounts of methylmercury also may be produced abiotically in sediment (Falter and Wilken, 1998). Maximum methylmercury production occurs at the oxic-anoxic boundary in sediment, usually several centimeters below the surface. Although less common, methylmercury also may be formed in anaerobic water (Regnell *et al.*, 1996 and 2001). In this case, mercury-methylating microbes move from the sediment to the overlying water and the resulting methylmercury becomes available to the biotic community when aerobic and anaerobic waters mix. Methylmercury is a byproduct of the metabolism of sulfate-reducing bacteria. The amount of methylmercury produced is a function of the amount of active bacteria, their available food, and conditions that affect bacterial growth, such as temperature and pH. Given conditions and food positive for growth, sulfate-reducing bacteria will produce methylmercury even if methylmercury is present in the surrounding environment (i.e., methylmercury production is not controlled by chemical equilibrium).

Demethylation is both a biotic and abiotic process. Both sulfate reducing and methanogen-type bacteria have been reported to demethylate mercury in sediment with maximum demethylation co-occurring in the same zone where maximum methylmercury production is located (Marvin-DiPasquale *et al.*, 2000). Photodegradation of methylmercury in the water column also has been observed (Sellers *et al.*, 1996; Byington *et al.*, 2005). While not well studied, the rate of both biotic and abiotic demethylation appear quantitatively important in controlling net methylmercury concentrations in aquatic ecosystems (Sellers and Kelly, 2001; Marvin-DiPasquale *et al.*, 2000).

Factors controlling sediment methylmercury production have been the subject of intense scientific research (for reviews see Wiener *et al.*, 2003b and Benoit *et al.*, 2003). Sediment factors and landscape events important in net methylmercury production include:

- Sulfate and pH concentration of the overlying water (Gilmour *et al.*, 1998; Miskimmin *et al.*, 1992; Krabbenhoft *et al.*, 1999);

- Percent organic content of the sediment (Krabbenhoft *et al.*, 1999; Miskimmin *et al.*, 1992; Hurley *et al.*, 1998; Heim *et al.*, 2003; Slotton *et al.*, 2003);
- Creation of new water impoundments (Verdon *et al.*, 1991; Bodaly *et al.*, 1997);
- Amount and kind of inorganic mercury present in the sediment (Krabbenhoft *et al.*, 1999; Bloom, 2003); and
- Amount of permanent or seasonally flooded wetland in a watershed (Krabbenhoft *et al*., 1999; Brumbaugh *et al*., 2001; St Louis *et al*., 1994 and 1996; Hurley *et al*., 1995).

The organic content of the sediment and the pH of the overlying water are not discussed further as neither appears controllable in the Delta.

3.1 Sulfate

Sulfate is used by sulfate reducing bacteria as the terminal electron acceptor in the oxidation of organic material. Sulfate additions have been observed to both stimulate (Gilmour *et al.*, 1992; King *et al.*, 2002) and inhibit (Benoit *et al.*, 1999; Gilmour *et al.*, 1998) methylmercury production. Addition of sulfate is predicted to stimulate methylmercury production when it is limiting. In contrast, sulfate amendments may inhibit production when excess sulfide is present. Sulfide is the primary byproduct in the reduction of sulfate and increasing sulfide concentrations may cause inhibition by either decreasing the amount of neutrally charged dissolved mercury-sulfide complexes[9] (Benoit *et al.*, 1999 and 2001, but see Kelley *et al.*, 2003, for conflicting results) or by precipitating insoluble mercuric sulfide (Compeau and Bartha, 1985).

Two factors influencing sulfate concentrations in the Delta are the water quality objectives for electrical conductivity (EC) and the ratio of San Joaquin River to Sacramento River water. Both are controllable water quality factors and result from water management decisions made by the State of California. Table 3 of Water Rights Decision 95-1WR stipulates maximum ambient electrical conductivity values for various locations in the Delta by month and water year type (SWRCB, 1995). Electrical conductivity in the Delta is primarily a function of freshwater outflow and seawater intrusion.[10] Water Right Decision 95-1WR regulates electrical conductivity by specifying both the amount of freshwater outflow and the amount of water exported to southern California. For example, during 2000-2001, the 2 o/oo salinity level[11] in ambient bottom water was located as far seaward as the City of Martinez in March 2000, but migrated as far upstream as Rio Vista in the summer of 2001 (Foe, 2003). The upstream movement of the salinity field had the effect of increasing sulfate concentrations in western Delta water by about ten-fold.

Sulfate concentrations are about seven times higher in the San Joaquin River than in the Sacramento River. At present, the San Joaquin River is almost entirely diverted out of the Delta by way of Old River and Grantline Canal for export to southern California via the State and Federal pumping facilities near Tracy. This reduces the proportion of San Joaquin River water

[9] Dissolved, neutrally charged mercury is the only form that readily crosses microbial cell membranes.

[10] Sulfate concentrations in the Sacramento and San Joaquin Rivers varied between 6-14 and 42-108 mg/l in 2000 and 2001 (Foe, 2003) while full strength seawater is 2,700 mg/l (Parsons and Takahashi, 1973).

[11] Salinity is generally reported in terms of parts per thousand (abbreviated o/oo), the number of pounds of salt per 1,000 pounds of water.

in much of the southern and central Delta and allows intrusion of Sacramento River water with lower sulfate concentrations. The Record of Decision for the CALFED Bay-Delta Program committed the State to evaluate and, if practical, begin construction of a series of permanent, operable barriers in the southern Delta to better control the routing of San Joaquin River water (CALFED Bay-Delta Program, 2004b). An indirect consequence of the permanent barriers is that their operation will determine sulfate concentrations in much of the central and southern Delta.

Sulfate amendment studies need to be undertaken with sediment collected throughout the year from the southern, central and western Delta to determine whether the sulfate concentration in the overlying water affect methylmercury production in sediment. Results of these experiments can be considered when evaluating how to manage the permanent, operable barriers in the southern Delta and when considering water right decisions to modify the location of the salinity field in the Delta.

3.2 New Water Impoundments

The creation of new water impoundments has been found to stimulate sediment microbial activity and to increase methylmercury concentrations in sediment, water and biota (Verdon *et al.*, 1991; Bodaly *et al.*, 1997). The State of California has a growing population and a limited water supply for municipal and agricultural use. One alternative under evaluation is the construction of additional reservoir storage. The Record of Decision for the CALFED Bay-Delta Program directs agencies and local interests to continue to evaluate five surface water storage options to improve water management (CALFED Bay-Delta Program, 2004a). These include north of Delta off-stream storage, in-Delta storage, Shasta Lake expansion, Los Vaqueros Reservoir expansion and upper San Joaquin storage. Environmental planning for each project is underway and should evaluate the potential of each new facility to increase downstream methylmercury concentrations in the Delta.

3.3 Sediment Mercury Concentrations

Methylmercury production has been found to be a function of the total mercury content of the sediment. Methylmercury concentrations[12] adjusted for the organic content of the sediment increased logarithmically with increasing total mercury concentration in a study of 106 sites from 21 basins across the United States (Krabbenhoft *et al.*, 1999). The slope of the relationship was linear to approximately 1 mg/kg total mercury before commencing to asymptote. Similar linear relationships have been observed in the Delta between methyl and total mercury concentrations in sediment (Table 3.1). The statistical significance of the correlation increases when data from one land use type (e.g., marshes) are used. This implies that methylation rates

[12] Radiotracer experiments in Florida Everglade sediment demonstrate that methylmercury production is positively correlated with bulk sediment methylmercury concentrations (Gilmour *et al.*, 1998). Moreover, the spatial pattern of methylmercury production was strongly correlated with aqueous and biotic concentrations, suggesting that surficial sediment concentrations could be used as an analog for *in situ* methylmercury production and flux into the overlying water. Bulk methylmercury sediment concentrations are now widely used as an index of methylmercury production (Krabbenhoft *et al.*, 1999; Bloom *et al.*, 1999 and 2003; Heim *et al.*, 2003; Slotton *et al.*, 2003; Conaway *et al.*, 2003; Benoit *et al.*, 1999).

may also be a function of habitat type. The results are consistent with laboratory experiments where increasing concentrations of inorganic mercury were amended into sediment and the evolution of methylmercury monitored. The efficiency of the conversion of total to methylmercury was linear to about 1 mg/kg before commencing to level off (Bloom, 2003; Rudd *et al.*, 1983).

Table 3.1: Field Studies Demonstrating a Positive Correlation Between Total Mercury and Methylmercury in Freshwater Surficial Sediment

Location [(a)]	R^2	P-Value	Comments	Author
Sacramento-San Joaquin Delta Estuary	0.2	<0.01	All habitats in Delta combined.	Heim *et al.*, 2003
Sacramento-San Joaquin Delta Estuary	0.52	<0.001	Only marsh habitats.	Heim *et al.*, 2003
Sacramento-San Joaquin Delta Estuary	0.37	<0.001	Comparisons inside and outside of flooded Delta Islands.	Slotton *et al.*, 2003
Elbe River	0.69	<0.0001	Germany.	Hintelmann & Wilken, 1995
Patuxent River Estuary	0.61	<0.05	Sub embayment of Chesapeake Bay.	Benoit *et al.*, 1998
National Survey	0.62	<0.0001	Log/log relationship normalized to percent organic carbon at 106 sites in 21 basins across the United States.	Krabbenhoft *et al.*, 1999
Lake Levrasjon	0.64	<0.05	Southern Sweden.	Regnell & Ewald, 1997

(a) The majority of the sediment in each study had a mercury content less than 1 ppm.

Mercury concentrations in fish at contaminated sites decline after control measures are instituted to reduce incoming mercury loads (Table 3.2). Most sites studied to date are industrial facilities that discharge to fresh water and have operated for relatively short periods.[13] The initial decrease in fish tissue concentration near the source of contamination is often fast with about a 50% decline in the first five to ten years. However, after a rapid initial decrease, concentrations tend to stabilize with little, if any, subsequent decline (Turner and Southworth, 1999; Takizawa, 2000; Lodenius, 1991; Lindestrom, 2001; Francesconi *et al*., 1997). The new equilibrium value is usually higher than in adjoining uncontaminated waterways and is also often greater than what is recommended as safe for human consumption (Turner and Southworth, 1999; Parks and Hamilton, 1987; Lodenius, 1991; Lindestrom, 2001; Francesconi *et al*., 1997; Becker and Bigham, 1995). The reasons are unclear but may be because small amounts of mercury are still entering from terrestrial sources (Turner and Southworth, 1999) or because of difficulties in bringing sediment concentrations down to background levels (Francesconi *et al*., 1997; Jernelov and Asell, 1975). If contamination has spread to areas more distant than the immediate facility, then reductions in fish tissue concentrations are much slower (Southworth *et al*., 2000). Absent from the literature are reports on remediation of pollution from mercury mining. The magnitude and duration of mercury and gold mining in

[13] One to two decades.

Table 3.2: Change in Fish Tissue Mercury Concentration After Initiation of Source Control.

Location	Mercury Source	Biotic Change	Control Measures	References
Oak Ridge National Laboratory, Tennessee	Weapons Facility	Sunfish at discharge point declined from 2 to 1 mg/kg in 5 yrs; half mile downstream sunfish declined from 0.9 to 0.7 mg/kg in 9 yrs; no change in tissue 2 and 5 miles downstream.	Reduced discharge, excavated portion of flood plain.	Turner & Southworth, 1999; Southworth *et al.*, 2000
Lake St. Clair, Michigan	Two Chloralkali Plants	Walleye fish declined from 2.3 to 0.5 mg/kg in 25 yrs	Reduced/eliminated discharge	Turner & Southworth, 1999.
Abbotts Creek, North Carolina	Battery Manufacturing plant	Fish declined from 1 to 0.5 mg/kg in 11 yrs	Treated groundwater, reduced/eliminated discharge, removed contaminated soil, natural sediment burial	Turner & Southworth, 1999
Saltville, Virginia	Chloralkali Plant	Rockfish declined from 3.5 to 1 mg/kg in 20 yrs	River sediment dredged, rock bottom grouted, rip-rap river bank, pond seepage treated with activated carbon	Turner & Southworth, 1999
Howe Sound, British Columbia, Canada	Chloralkali Plant	Dungeness crab declined from 2 to 0.2 mg/kg in 5 yrs. No subsequent change	Reduced/eliminated discharge, treated groundwater	Turner & Southworth. 1999
Little Rock Lake, Wisconsin	Atmospheric deposition	Yellow Perch declined 30% in 6 yrs	Reduced atmospheric mercury input by 60%.	Hrabik & Watras, 2002.
Minimata, Japan	Chloralkali Plant	Fish declined from 9.0 to 0.4 mg/kg in 8 yrs; no further change.	Eliminated discharge; dredged and disposed of sediment.	Takizawa, 2000
Clay Lake, Ontario, Canada	A chloralkali plant and a wood pulp mill.	Walleye fish declined from 15.1 to 2.0 mg/kg in 20 yrs. Background concentration is 0.6 mg/kg.	Eliminated discharge; natural burial of contaminated sediment	Parks & Hamilton, 1987; Turner & Southworth, 1999.
Ball Lake, Ontario, Canada (downstream of Clay Lake)	Same as above	Walleye fish declined from 2.0 to 1.4 mg/kg in first 5 yrs. Northern Pike from 5.1 to 1.8 mg/kg. No change in Lake Whitefish.	Same as above	Armstrong & Scott, 1979
Lake Kirkkojarvi, Finland	Phenylmercury in slimicide in pulp mill	4 and 1-kg Northern Pike declined from 3.6 to 2.1 and from 1.5 to 0.8 mg/kg in 20 yrs. All reductions happened in first 10 yrs. Background concentration in 1-kg pike is 0.4 mg/kg.	Reduced discharge, natural burial	Lodenius, 1991
Lake Vanern, Sweden	Chloralkali Plant	5-yr old Northern Pike declined from 1.4 to 0.6 mg/kg in 25 yrs. Most of decrease occurred in first 10-15 yrs. Background concentrations in Pike are 0.4 mg/kg	Reduced/eliminated discharge, natural burial	Lindestrom, 2001
Princess Royal Harbor, Australia (Marine water)	Superphosphate Processing Plant	Mercury in 8 marine fish species declined by about 50% in 9-yrs. Most of decrease happened in first 4-yrs. Tissue concentrations are still about twice background.	Eliminated discharge, natural burial	Francesconi *et al*., 1997
Onondaga Lake, New York	Municipal and industrial discharge	Mercury in six fish species declined by 60 to 80 % in 22 yrs. Tissue concentrations are still about twice background.	Eliminated discharge, natural burial	Becker & Bigham, 1995.
North Carolina, Quebec, Finland, Manitoba, Labrador and Newfoundland	Reservoir creation	Fish tissue levels declined to normal after 3 to 30 years.	None	As reviewed in French *et al*., 1998.

California, coupled with the extensive distribution of contamination, will likely make recovery much slower than at industrial sites (Table 3.2).

As part of the mercury control program for San Francisco Bay, San Francisco Water Board staff established a goal for Bay sediment of 0.2 mg/kg mercury and assigned Central Valley outflows a total mercury load reduction of 110 kg per year to achieve it (Johnson and Looker, 2004; SFBRWQCB, 2006). Waterborne mercury and total suspended sediment loads in the Delta's tributaries are summarized in Chapter 7. Initial management actions of the Delta methylmercury TMDL could consider controlling mercury from watersheds with high methylmercury concentrations in fish, high mercury to suspended sediment ratios and large areas of downstream marsh. The initial goal would be to meet the San Francisco Water Board's goal of 110 kg total mercury reduction per year, but additional load reductions eventually may be needed to achieve compliance with the recommended fish tissue mercury targets for the Delta (Chapter 4).

3.4 Forms of Mercury

Two different forms of mercury are transported into the Delta with potentially different methylation rates. The first form is mercury mine waste from the Coast Range. Most of this material is thought to be mercuric sulfide, cinnabar and metacinnabar (Bloom, 2003). Mercury mine waste enters the Delta from mine-impacted coast range creeks such as Putah and Cache Creeks. The second form is elemental mercury lost from placer and hardrock gold mining operations in the Sierra Nevada Mountains. Elemental mercury enters the Delta in Sacramento, Mokelumne and San Joaquin River water that drains from the northern and southern gold fields.

Mercury from gold mining appears to be more biologically available than material from mercury mines. The evidence is twofold. First, Frontier Geosciences conducted a 1-year microcosm incubation study with both gold and mercury mine waste to determine the relative methylation efficiency of each (Bloom, 2003). Mercury from gold mining was found to have the higher methylation rate. Second, the ratio of methyl to total mercury in natural sediment is assumed to be a field measure of methylation efficiency (Gilmour *et al.*, 1998; Krabbenhoft *et al.*, 1999; Bloom *et al.*, 1999 and 2003). Heim and others (2003) collected sediment at multiple locations in Cache Creek (representative of mercury mine waste) and the Cosumnes River (representative of gold mine material) on three occasions (October 1999, May 2001 and October 2001) to determine methyl and total mercury concentrations and methylation efficiencies. The highest methyl to total mercury ratios were consistently observed in Cosumnes River material. These results are consistent with the conclusions of Bloom (2003) and suggest that floured elemental mercury from gold mining in the Sierra Nevada is more readily methylated than is cinnabar from the Coast Range.

Heim and others (2003) also collected sediment samples at multiple locations in Cache Creek. The ratio of methylmercury to total mercury increased with increasing distance from the mercury mining districts. The authors speculate that diagenic weathering-type processes are changing the form of the mercury and increasing its methylation efficiency as the material is slowly transported away from the mines. The precise mechanisms are not known but may include the formation of soluble polysulfide complexes (Paquette and Heltz, 1995) and dissolution of cinnabar by humic and fulvic acids (Wallschläger *et al.*, 1998; Ravichandran *et al.* 1998). Both processes should increase the efficiency of the conversion of inorganic to organic mercury. No similar weathering type experiments have been conducted on Sierra Nevada gold mine-derived mercury. The Cache Creek findings suggest that there is currently insufficient understanding of mercury weathering processes to justify developing control programs that preferentially target controlling gold-mine waste material.

3.5 Wetlands

Research in the Delta and elsewhere has found that wetlands are sites of efficient methylmercury production (Slotton *et al.*, 2003; Heim *et al.*, 2003; St. Louis *et al.*, 1994, 1996; Gilmour *et al.*, 1998). In fact, one of the best predictors of methylmercury concentrations in water and in biota is the amount of wetland present in upstream watersheds (Krabbenhoft *et al.*, 1999; Wiener *et al.*, 2003b). The Record of Decision for the CALFED Bay-Delta Program commits it to restore 30,000 to 45,000 acres of fresh, emergent tidal wetlands, 17,000 acres of fresh, emergent nontidal wetlands, and 28,000 acres of seasonal wetlands in the Delta by 2030 (CALFED Bay-Delta Program, 2000b). This is a total of 75,000 to 90,000 acres of additional seasonal and permanent wetlands in the Delta, which represents about a three to four times increase in wetland acreage from current conditions. Many of the proposed restoration sites are downstream of mercury-enriched watersheds. Marsh restoration efforts below mercury enriched watersheds are proposed for the following locations: Yolo Bypass downstream of Cache and Putah Creeks; Dutch Flats downstream of the Mount Diablo Mercury mine in the Marsh Creek watershed; and Staten Island and the Cosumnes River Wildlife Refuge near the confluence of the Cosumnes River and Mokelumne River. Extensive restoration efforts in the Delta have the potential to increase methylmercury exposure for people and wildlife. This potentially significant adverse environmental impact was identified in CALFED's programmatic ROD's CEQA evaluation.

Even though much of the research has found that wetlands act as sources of methylmercury, recent preliminary data indicates that some wetlands may act as net methylmercury sinks. Table 3.3 provides a summary of methylmercury production characteristics from different types of wetlands in the Delta region. In addition, a technical review of the June 2006 TMDL Report described a study conducted in southern Florida, in which different wetland and open water sites were found to contain varying levels of methylmercury (Tetra Tech, Inc., 2006). More research is needed to understand the processes that affect a wetland's methylmercury production, so that wetland restoration can occur with minimal methylmercury production increases.

Table 3.3: Summary of Wetland Methylmercury Production Characteristics (Preliminary Results).

Watershed	Site [a]	Wetland Type	MeHg Characteristics [b]
Delta	Twitchell Island (1)	2 Permanent (test ponds)	Both sources (one with 10x the summer production)
	Browns Island (2)	Permanent, tidal	Small source
	Sycamore Slough (2)	Permanent, tidal	Sink
Cache Creek	Anderson Marsh (3)	Permanent	Source
	Cache Creek Nature Preserve (4)	Permanent	Source
Mud Slough	San Luis Wildlife Refuge (5)	2 Permanent	Both neutral
		6 Seasonal	All sources
Suisun Marsh	First Mallard Branch (interior marsh) (2)	Permanent, tidal	Source
	Suisun Slough (mouth) (2)	Permanent, tidal	Sink

(a) Study citations: (1) Sassone *et al*., 2006; (2) Stephenson *et al*., 2006; (3) CVRWQCB, unpublished data; (4) Slotton and Ayers, 2001; (5) Stephenson *et al*., 2007.

(b) Wetlands that act as net producers of methylmercury are noted as "sources"; wetlands that act as sinks for methylmercury (e.g., more methylmercury is imported than exported) are noted as "sink"; and wetlands that apparently acted as neither a source nor sink for methylmercury are noted as "neutral".

Key Points

- The problem with mercury in the Delta's aquatic ecosystems can be defined as biotic exposure to methylmercury. Therefore, decreasing biotic exposure to methylmercury is the ultimate goal of the Delta methylmercury TMDL and implementation program.
- The implementation plan should focus on sources and processes that are potentially controllable in the Delta. Potentially controllable sediment factors and landscape events important in net methylmercury production include: water rights salt standards in the Delta; creation of new water impoundments; amount of inorganic mercury present in the sediment; and amount of permanent or seasonally flooded wetland in a watershed.

4 NUMERIC TARGETS

Water quality targets for mercury in fish were calculated to protect beneficial uses of the water and aquatic resources of the Delta. The targets are intended to reduce the risks to humans and wildlife that consume fish and other aquatic organisms from the Delta that contain methylmercury. This chapter first describes the derivation of species-specific targets based on a suite of fish types to protect humans and wildlife. The Central Valley Water Board staff proposes three targets for the protection of human and wildlife health: 0.24 mg/kg (wet weight) in muscle tissue of large trophic level four (TL4) fish such as bass and catfish; 0.08 mg/kg (wet weight) in muscle tissue of large TL3 fish such as carp and salmon; and 0.03 mg/kg (wet weight) in whole trophic level 2 and 3 fish less than 50 mm in length. In addition, staff proposes an implementation goal of 0.24 mg/kg methylmercury, wet weight, in standard 350-mm largemouth bass. As described in Chapter 5, this implementation goal can be linked to aqueous methylmercury to develop an implementation goal for methylmercury in unfiltered ambient water, which in turn can be used to determine methylmercury source reductions needed to achieve the proposed targets for methylmercury in fish.

In addition to addressing sources of methylmercury to the Delta, the Delta mercury control program addresses total mercury sources to the Delta and San Francisco Bay. The San Francisco Bay TMDL assigns a load reduction of 110 kg per year from the Central Valley (Johnson and Looker, 2004). As described in later chapters of this report, the mercury control program for the Delta is designed to achieve the total mercury load reduction required by the San Francisco Water Board, as well as to maintain compliance with the USEPA's CTR for total mercury in freshwater sources and to limit total mercury sources to the Delta to ensure that methylmercury levels in fish do not increase in the future.

4.1 Definition of a Numeric Target

Numeric targets are the specific goals for the TMDL that will enable the protection of the beneficial uses of the Delta and San Francisco Bay. The development of numeric targets involves the following elements:

- Identification of the target media and the basis for using the selected target media to interpret or apply applicable water quality standards.
- Identification of target levels for the selected target media and the technical basis for the target levels.
- Comparison of historical or existing conditions and desired future conditions for the target media selected for the TMDL.

4.2 Clean Water Act 303(d) Listing and Beneficial Use Impairment

The Office of Environmental Health Hazard Assessment issued health advisories recommending that consumers limit their consumption of striped bass and sturgeon from the Delta and Bay because of high methylmercury tissue concentrations (Section 2.4.1). The fish advisory resulted in the Central Valley and San Francisco Water Boards listing the Bay-Delta Estuary as impaired.

By definition, an impaired water body does not support all of its designated beneficial uses. Existing and potential beneficial uses are listed in Table 2.3 in Chapter 2. The Delta provides habitat for warm and cold water species of fish and the aquatic communities associated with them. In addition, the Delta and associated riparian areas provide valuable wildlife habitat. Beneficial uses that are impaired due to high mercury levels include commercial and sport fishing and wildlife habitat.

4.3 Selection of the Type of Target for the Delta

4.3.1 Fish Tissue

Measurements of mercury in the target media should be able to assess fairly directly whether beneficial uses are being met. Several media for numeric targets were considered, including sediment, water column and biota. The major beneficial use of the Delta that is currently unmet is its use as a safe fishery for humans and wildlife. A target of mercury in fish tissue was determined to be the most appropriate because it provides the most direct assessment of fishery conditions and improvement. Fish tissue data have been collected between 1969 and 2002 in the Delta. Existing data for fish species consumed by humans and wildlife provide a baseline against which future improvements can be measured.

Targets are developed for **methylmercury** in fish tissue because it is the most toxic form of mercury. It is also the form to which humans and wildlife may be exposed in the Delta at levels sufficient to cause adverse effects. The cost for methylmercury analysis is greater than that for total mercury; therefore, most data available are for total mercury in fish tissue. Independent research demonstrates that most mercury (85-100%) in fish muscle is methylmercury (Becker and Bigham, 1995; Slotton *et al.*, 2004). For the purposes of the TMDL, Central Valley Water Board staff assumes that all the mercury measured in Delta fish is methylmercury.

4.3.2 San Francisco Bay Numeric Target

The Delta TMDL is structured to meet the San Francisco Bay mercury TMDL's total mercury allocation for Central Valley outflows to the Bay. San Francisco Water Board staff developed a target for San Francisco Bay sediment mercury concentration of 0.2 mg/kg and assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr at Mallard Island or a decrease of 110 kg/yr in mercury sources to the Delta. The 2004 San Francisco Bay mercury TMDL staff report provides a detailed derivation of the San Francisco Bay sediment target and allocation for the Central Valley (Johnson and Looker, 2004). Strategies for reducing the total mercury loading to San Francisco Bay are discussed in Chapter 8 in this TMDL report and Chapter 4 in the draft Basin Plan Amendment staff report.

4.3.3 Water Criteria

The California Toxics Rule (CTR) mercury criterion applies to the Delta (see Section 2.3.2.2). This criterion of 50 ng/l total recoverable mercury in water is intended to protect the health of humans consuming contaminated organisms and drinking water. The CTR value may not be sufficiently protective of humans consuming fish from the Delta because of the low bioconcentration factors used to derive the CTR value. Central Valley Water Board staff considers fish tissue targets to be more stringent than the CTR criterion.[14] Although the CTR criterion may be less protective than the fish tissue targets discussed below, the TMDL was designed to comply with the CTR mercury criterion. Compliance with the CTR criterion through the TMDL is discussed in the total mercury source assessment (Chapter 7) and total mercury limits (Chapter 8) sections of this report.

4.4 Fish Tissue Target Equation and Development

Key variables that are incorporated into the calculation of fish tissue targets are:

- Acceptable daily dose level of methylmercury;
- Body weight (bwt) of the consumer;
- Trophic level or size of fish consumed; and
- Rate of fish consumption.

These components can be related using a basic equation (OEHHA, 2000; USEPA, 1995c) as follows.

Equation 4.1:

$$\frac{\text{Safe daily intake * Consumer's body weight}}{\text{Consumption rate}} = \text{Acceptable level of mercury in fish tissue}$$

At or below the safe daily intake of methylmercury, consumers are expected to be protected from adverse effects. An acceptable intake level is also called a reference dose (RfD). An RfD is expressed as an average daily rate (micrograms of mercury per kilogram body weight per day) of mercury intake. In general, an RfD is calculated by using studies of exposure in specific populations to determine a threshold level of exposure below which adverse effects did not occur. The threshold level is then divided by uncertainty factors that lower the value to the final reference dose. Uncertainty factors account for differences in metabolism and sensitivity between individuals, lack of toxicity information in available studies, or other unknowns.

In the calculation of its recommended methylmercury criterion to protect human health, USEPA added a relative source contribution (RSC) component to the equation to account for methylmercury from other sources (USEPA, 2001). Humans are exposed to methylmercury

[14] The weighted average practical bioconcentration factor (PBCF) used to develop the CTR mercury criterion is 7342.6 (USEPA, 2000b). For the Delta, bioaccumulation factors (BAF) for large trophic 4 fish are in the range of 50,000 to 300,000. These BAFs are the ratios of mercury in fish to the concentration of total recoverable mercury in water. The Delta bioaccumulation factors indicate that piscivorous fish species in the Delta accumulate higher concentrations of mercury than USEPA's PBCF.

from commercial fish as well as locally caught fish. Human intakes of methylmercury from all other sources (air, drinking water, soil, and foods other than fish and seafood) are considered negligible. The RSC represents that portion of methylmercury exposure that will not be controlled by cleanup actions directed to a particular water body. Because piscivorous wildlife species are assumed to obtain all of their fish or other aquatic prey from the local water body, no RSC adjustment is used for the wildlife calculations. As with humans, the direct intake of methylmercury by piscivorous wildlife from air or water is negligible relative to intake from fish and aquatic organisms (USEPA, 1997a).

The consumption rate can be separated into rates of consumption of fish from each trophic level. Adjusting for multiple consumption rates and the RSC, the basic equation appears as follows.

Equation 4.2:

$$\frac{(\text{Safe intake} - \text{RSC}) * \text{body weight}}{(\text{CRate}_{TL2} + \text{CRate}_{TL3} + \text{CRate}_{TL4})} = \text{Acceptable level of mercury in Delta fish tissue}$$

Where: CRate_{TL2} = consumption rate of fish from Trophic Level 2
CRate_{TL3} = consumption rate of fish from Trophic Level 3
CRate_{TL4} = consumption rate of fish from Trophic Level 4

Safe levels of methylmercury in fish tissue that protect wildlife are presented first in this report, followed by the human health targets. The order of presentation and in-depth discussion of wildlife methodology are not intended to suggest greater importance of wildlife targets relative to human health targets. Rather, wildlife targets are discussed first because the safe fish tissue levels are based on average consumption rates that are assumed to be constant. Human consumption rates, however, vary widely by individual. For targets to protect human consumers, consumption rate options are incorporated into the calculations.

4.5 Wildlife Health Targets

Birds and mammals most likely at risk for mercury toxicity are primarily or exclusively piscivorous. Those identified for the Delta are: American mink, river otter, bald eagle, kingfisher, osprey, western grebe, common merganser, peregrine falcon, double crested cormorant, California least tern, and western snowy plover[15] (USEPA, 1997a; CDFG, 2002). Bald eagles, California least terns and peregrine falcons are listed by the State of California or by the USFWS as either threatened or endangered species. The Delta is a foraging and possible wintering habitat for bald eagles (USFWS, 2004). California least terns also forage in the Delta. There is at least one nesting colony of these terns within the Delta (USFWS, 2004).

[15] The CDFG *California Wildlife Habitat Relationships* database also reports observations of brown pelicans and clapper rails in the Delta. Both of these species are federally listed as endangered and depend on the aquatic food web. However, it has been confirmed that brown pelicans and clapper rails prefer saltwater habitats and are only occasional visitors to the Delta regions as discussed in this TMDL (Schwarzbach, 2003; CDFG, 2005). Peregrine falcon are included because they consume piscivorous waterfowl.

Although most of the Delta habitat is unlike that preferred by peregrine falcons for nesting, several peregrine falcon pairs have nested on bridges in the area (Linthicum, 2003).

Acceptable fish tissue mercury levels for wildlife species can be calculated using daily intake levels, body weights and consumption rates. Parameters needed to estimate daily methylmercury exposures and safe levels of methylmercury in prey for wildlife are given in Table 4.1. Mercury studies conducted in the laboratory and field are used to derive RfD for birds and mammalian wildlife. The following section uses these RfDs to calculate fish tissue targets to protect the health of wildlife in the Delta.

4.5.1 Reference Doses, Body Weights & Consumption Rates

The reference dose for mammalian wildlife species of 0.018 mg methylmercury/kg bwt/day is based on studies in which mink were fed methylmercury at varying doses and evaluated for neurological damage, growth and survival (USEPA, 1995a; USEPA, 1997b). Studies of mallard growth and reproduction following methylmercury exposure were used to determine a methylmercury reference dose for birds of 0.021 mg/kg bwt/day (USEPA, 1997b).

Average body weights of adult females are used because the most sensitive endpoints of methylmercury toxicity are related to reproductive success. The USFWS provided guidance to Central Valley Water Board staff regarding the species of concern and their exposure parameters (USFWS, 2002, 2003 and 2004).

4.5.2 Safe Methylmercury Levels in Total Diet

Fish tissue mercury levels that would result in methylmercury intakes by piscivorous wildlife at or below safe intake levels are calculated in two steps. First, safe levels of methylmercury in the total diet of each wildlife species are calculated (Table 4.2). The total diet safe level represents the concentration of methylmercury, as an average in all prey consumed, needed to keep the organism's daily intake of methylmercury below the reference dose. Total diet safe levels were calculated using the exposure parameters for wildlife species and Equation 4.1. In the second step, the total diet safe level is translated into protective levels of methylmercury in various components of an organism's diet (Table 4.3). An example calculation of the total safe diet level for mink is shown below:

$$\frac{\text{Mammalian reference dose * Mink body weight}}{\text{Mink fish consumption rate}} = \text{Total diet safe level}$$

$$\frac{18\ \mu\text{g MeHg/kg day * 0.60 kg}}{140\ \text{g/day}} = 0.077\ \mu\text{g MeHg/g total diet (0.077 mg/kg)}$$

Table 4.1: Exposure Parameters for Fish-Eating Wildlife

Species [a]	Body weight [b]	Total Food Ingestion Rate [c]	Trophic Level 2 Aquatic Prey	Trophic Level 3 Aquatic Prey	Trophic Level 4 Aquatic Prey	Piscivorous Bird Prey	Omnivorous Bird Prey	Other Foods [d]	Size of Prey
	kg	g/day, wet wt	g/day, as % of diet	g/day, as % of diet	g/day, as % of diet	g/day, as % of diet	g/day, as % of diet	g/day, as % of diet	
Mink	0.60	140	-	140 (100%)	-	-	-	-	most prey 50-150mm; females catch smaller prey than males (USEPA, 1995b)
River otter	6.70	1124	-	899 (80%)	225 (20%)	-	-	-	heterogeneous, 20-500 mm (USEPA, 1995b); majority <150 mm but commonly catch large TL4 fish.
California least tern	0.045	31	-	31 (100%)	-	-	-	-	mostly < 50 cm, nearly all fish
Western snowy plover	0.041	33.3	8.3 (25%)	-	-	-	-	25 (75%)	mainly aquatic and terrestrial invertebrates. Assume TL2 aquatic prey is 25% of diet (USFWS, 2003)
Belted kingfisher	0.15	68	-	68 (100%)	-	-		-	generally less than 105 mm; up to 180 mm (Hamas, 1994)
Common merganser [e]	1.23	302	-	302(100%)	-	-	-	-	most prey <150 mm (USEPA, 1995b; Hatch & Weseloh, 1999)
Double-crested cormorant [f]	1.74	390	-	390 (100%)	-	-	-	-	generally 100-300 mm length; up to 360mm (Mallory & Metz, 1999)
Western grebe [g]	1.19	296	-	296 (100%)	-	-	-	-	USFWS assumed similar to merganser (USFWS, 2004)
Bald eagle [h]	5.25	566	-	328 (58%)	74 (13%)	28 (5%)	74 (13%)	62 (11%)	fish 75-500+ mm; most will be >150 mm (Jackman *et al.*, 1999; USEPA, 1995b).
Osprey [i]	1.75	350	-	315 (90%)	35 (10%)	-	-	-	fish 100-450 mm; most will be >200 mm.
Peregrine falcon [j]	0.89	134	-	-	-	6.7 (5%)	13.4 (10%)	114 (85%)	Does not eat fish.

Table 4.1 Footnotes:

(a) Italics denote species listed as threatened or endangered by State or Federal authorities.

(b) Average female body weights are from *Trophic Level and Exposure Analyses for Selected Piscivorous Birds and Mammals Volume II* (USEPA, 1995b), USFWS (2003, 2004), and as noted below.

(c) Total food ingestion rates are from USEPA (1995b) and USFWS (2003; 2004) and as noted below.

(d) Other foods are mainly terrestrial mammal, bird, reptile and invertebrate prey that are presumed to provide negligible amounts of methylmercury.

(e) Merganser body weight and ingestion rate from Schwarzbach and others (2001).

(f) Cormorant body weight is the average for female birds cited in Hatch and Weseloh (1999). This paper also reports daily consumption at 20-25% of body mass. Total ingestion rate of 390 g/day is 22.5% of average female bodyweight.

(g) Female western grebe body weight from Storer and Nuechterlein (1992).

(h) Bald eagle parameters provided by the USFWS (2004). Diet of bald eagles in northern California includes fish, mammals and birds. Using dietary data from Jackman and others (1999), the USFWS estimated the average proportions of prey types. TL3 and TL4 fish comprised 58% and 13% of the total bald eagle diet, respectively. Piscivorous birds, such as gulls, grebes, and mergansers, comprised approximately 5% of the total diet. An additional 13% of the total diet was comprised of other aquatic birds, such as coots, that feed mainly on TL2 organisms. Bald eagles are scavengers and thus consume fish of large sizes (Jackman *et al.*, 1999).

(i) Osprey catch and eat large fish, the majority of which are >200 mm (USEPA, 1995b). In a water body where TL4 sport fish are readily available, osprey diet is assumed to be 10% TL4 fish (USFWS, 2002). Prey size is limited to the maximum size that an osprey can lift out of water.

(j) Peregrine falcons eat a wide variety of birds, including grebes, herons, shorebirds, mergansers, gulls and other birds that accumulate methylmercury from the aquatic food web. USFWS (2004) supports the assumption by Central Valley Water Board staff that approximately 15% of peregrine prey in the Delta area is comprised of piscivorous birds. See the appendices of the Cache Creek TMDL for Mercury staff report for further analysis of peregrine prey and habitat.

Table 4.2: Concentrations of Methylmercury in Total Diet to Protect Delta Wildlife Species

Species	**RfD** (µg/kg bwt-day)	**Body Weight** (kg)	**Total Food Ingestion Rate** (g/day)	**Safe Methylmercury Concentration in Total Diet** (mg/kg in diet)
Mink	18	0.60	140	0.077
River otter	18	6.70	1124	0.11
California least tern	21	0.045	31	0.030
Western snowy plover	21	0.041	33.3	0.026
Belted kingfisher	21	0.15	68	0.046
Common merganser	21	1.23	302	0.086
Double-crested cormorant	21	1.74	390	0.094
Western grebe	21	1.19	296	0.084
Bald eagle	21	5.25	566	0.20
Osprey	21	1.75	350	0.11
Peregrine falcon	21	0.89	134	0.14

Table 4.3: Safe Concentrations of Methylmercury in Fish (mg/kg) by Trophic Level to Protect Wildlife

Species [(a)]	TL 2, < 50 mm	TL 2-3, 50-150 mm	TL 3, 150-350 mm	TL 4, 150-350 mm	TL 3, >150 mm	TL 4, >150 mm
Mink		0.08				
River otter		0.04		0.36		
California least tern	0.03					
Western snowy plover [(b)]	0.10					
Belted kingfisher		0.05				
Double-crested cormorant		0.09				
Common merganser			0.09			
Western grebe			0.08			
Osprey			0.09	0.26		
Bald eagle [(c)]					0.11	0.31
Peregrine falcon [(d)]			(0.17)			

(a) Italics denote species that are listed as threatened or endangered by Federal or State authorities.
(b) The snowy plover safe level should be applied to TL2/3 aquatic invertebrates, such as small clams, crabs, polychaetes and amphipods.
(c) To avoid exceeding the bald eagle wildlife value, safe concentrations must be attained in birds as well as fish eaten by bald eagles. The safe levels for average mercury concentrations in omnivorous and piscivorous bird prey are 0.19 and 1.35 mg/kg, respectively. Because bald eagles are scavengers, there is no upper size limit on fish eaten by these birds.
(d) Parentheses denote the TL3 fish level corresponding to the piscivorous bird safe concentration for peregrines. For birds eaten by peregrine falcons, the average concentrations should not exceed 2.2 mg/kg in piscivorous bird prey, respectively.

4.5.3 Calculation of Safe Fish Tissue Levels from Total Diet Values

Wildlife species consume fish and other aquatic prey from various size ranges and trophic levels. In the second step of wildlife target development, safe fish tissue levels are identified for different prey classifications. These classifications are termed “trophic level food groups”. Table 4.3 shows safe fish tissue concentrations needed by the wildlife species and developed for prey within the following trophic level food groups: TL2 fish less than 50 mm in length, 50-150 mm TL2 and 3 fish, 150-350 mm TL3 fish, and TL4 fish greater than 150 mm.

In cases in which an organism’s prey is fairly uniform and from one trophic level, the total diet safe level becomes the average, safe tissue mercury concentration. For organisms that feed from different trophic levels, the proportions of each trophic level in the diet (Table 4.1) are used to determine safe tissue mercury levels for each component of the diet. The species whose prey falls generally into one size category are mink, California least tern, western snowy plover, double crested cormorant, western grebe, kingfisher and common merganser. For these species, the total diet safe level becomes the safe fish tissue level matched to the size and trophic level of prey consumed.

Average, safe fish tissue concentrations for kingfisher, cormorant and mink were determined for the food group size range of 50-150 mm. Although kingfishers typically consume fish less than 105 mm in length, they can eat fish as long as 180 mm (Hamas, 1994; USEPA, 1995b). The range for cormorant prey is 30 to 400 mm, with most fish eaten being less than 150 mm (Hatch and Weseloh, 1999). Most fish caught by mink are in the range of 50-150 mm (USEPA, 1995b).

As the size ranges of prey caught by these three species are similar, one category of TL2/3 fish is appropriate for their protection (USFWS, 2004).

A second food group of TL3 fish in the range of 150-350 mm incorporates safe fish tissue mercury concentrations for prey of common mergansers and western grebes. Most prey caught by mergansers is in the range of 100-300 mm, with catches of fish up to 360 mm observed (Mallory and Metz, 1999). Because body size and foraging strategy of western grebes are similar to those of the merganser, staff assumed the same size range for grebe prey (USFWS, 2004).

Otter, bald eagle and osprey eat fish from multiple trophic level food groups. Methylmercury concentrations vary as a function of size and trophic level of prey. Therefore, different trophic levels of prey will have different acceptable concentrations of methylmercury. For these wildlife species, the total diet safe level (TDSL) can be described as:

Equation 4.3:

$$TDSL = (\%\ diet\ TL_2 * TL2_{conc}) + (\%\ diet\ TL_3 * TL3_{conc}) + (\%\ diet\ TL_4 * TL4_{conc})$$

Where: $\%\ diet\ TL_2$ = percent of trophic level 2 biota in diet

$\%\ diet\ TL_3$ = percent of trophic level 3 biota in diet

$\%\ diet\ TL_4$ = percent of trophic level 4 biota in diet

$TL2_{conc}$ = concentration of methylmercury in TL2 biota

$TL3_{conc}$ = concentration of methylmercury in TL3 biota

$TL4_{conc}$ = concentration of methylmercury in TL4 biota

In order to solve the above equation for the desired concentrations in TL2, TL3 and TL4 biota, concentrations in two trophic levels are put in terms of the concentration in the lowest trophic level. Equation 4.3 is then rearranged to solve for the lowest trophic level concentration.

In order to express the concentration in a higher trophic level (i.e., TL4) in terms of TL2 concentrations, staff used two types of translators: food chain multipliers (FCM) and trophic level ratios (TLR).[16] FCM and TLR used in the calculation of Delta wildlife targets are shown in Table 4.4. Where possible, site-specific, existing fish concentration data was used to develop the ratios. A similar table of safe fish tissue concentrations to protect wildlife species using a national average bioaccumulation factor (BAF) between TL3 and TL4 of five is presented in Chapter 6 of Mercury Study Report to Congress Vol. 7 (USEPA, 1997b). Details regarding the calculation of the translators and their use were provided by the USFWS (2003 and 2004).

---

[16] A food chain multiplier (FCM) is the ratio of methylmercury concentrations in fish of different trophic levels. A FCM represents the biomagnification of mercury between 2 successive levels of the food chain. The FCM is determined using mercury concentration data in fish in a predator-prey relationship. Example: the FCM for trophic level 4 fish is the ratio of methylmercury in large TL4 fish to methylmercury in small TL3 fish.

A trophic level ratio (TLR) is the ratio of methylmercury concentrations in fish of different trophic levels, but is derived using data for fish in the same size classification. For example, an osprey may consume sunfish (TL3) and bass (TL4). A 350 mm sunfish, though, is too large to be preyed upon by an equivalently-sized smallmouth bass. Therefore, the ratio of mercury concentration in TL4 to TL3 fish eaten by osprey is termed a TLR rather than a FCM.

Table 4.4: Food Chain Multipliers and Trophic Level Ratios for Delta Wildlife Target Development

Translator	Value	Source	Relevant Wildlife Species [a]
Trophic Level Ratio (TLR)			
TLR 4/3	3.0	Ratio between existing MeHg concentrations in large TL4 fish (150-350 mm length) and large TL3 fish (150-350 mm length). Calculated from Delta-wide average fish tissue levels; see Appendix B.	Bald eagle, osprey
Food Chain Multipliers (FCM)			
FCM 4/3	8.1	Ratio between existing MeHg concentrations in large TL4 fish (150-350 mm length) and small TL3 fish (50-150 mm). Calculated from Delta-wide average fish tissue levels; see Appendix B.	River otter
FCM 3/2	5.7	Ratio between MeHg concentrations in large TL3 fish and small TL2 fish. From USFWS (2004) based on national averages.	Bald eagle, peregrine falcon
FCM piscivorous birds (FCM PB)	12.5	Ratio between MeHg in piscivorous bird tissue and in small TL3 prey fish. From USFWS (2003).	Bald eagle, peregrine falcon
FCM omnivorous birds (FCM OB)	10	Ratio between MeHg in omnivorous bird tissue and in small, TL2/3 prey fish and other aquatic organisms. From USFWS (2003).	Bald eagle, peregrine falcon

(a) Wildlife species for which the translator is used to determine safe tissue levels.

4.5.3.1 River Otter Safe Tissue Levels

To calculate the safe concentrations for otter, the safe concentrations in TL3 and TL4 fish need to be determined. In order to solve for these two variables using Equation 4.3, the TL4 fish concentration is expressed in terms of the TL3 fish concentration. River otters eat a wide range of prey sizes. Large fish in the otter diet likely prey on small fish that otter also eat. Therefore, the TL4 variable is expressed using the TL3 concentration and a food chain multiplier (FCM 4/3). From the Delta field data, staff determined that the methylmercury concentration in large TL4 fish is 8.1 times the concentration in small TL3 fish. Safe tissue levels in TL3 and TL4 fish for otter are determined by:

$$TDSL_{otter} = (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc})$$

Where: $TL4_{conc} = TL3_{conc} * FCM\ 4/3$

$$0.107\ mg/kg = (0.80 * TL3_{conc}) + (0.20 * 8.1 * TL3_{conc})$$

Solving for $TL3_{conc}$:

$$TL3_{conc} = 0.044\ mg\ MeHg/kg\ fish$$

$$TL4_{conc} = 0.044\ mg/kg * 8.1 = 0.36\ mg\ MeHg/kg\ fish$$

This equation produces safe levels of 0.04 and 0.36 mg/kg in small TL3 and large TL4 fish, respectively, which are shown in Table 4.3.

4.5.3.2 Osprey safe tissue levels

Safe methylmercury tissue levels for osprey are calculated like those for river otter, with the exception of the trophic level translator. Trophic level 3 and 4 fish eaten by osprey tend to be of similar sizes. Because there is not a food chain relationship between similarly sized fish, the osprey values are calculated using a trophic level ratio (TLR 4/3). On average in the Delta, methylmercury levels in large TL4 fish are 3.0 times the levels in large TL3 fish.

$$TDSL_{osprey} = (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc})$$

Where:

$$TL4_{conc} = TL3_{conc} * TLR\ 4/3$$

$$0.105\ mg/kg = (0.90 * TL3_{conc}) + (0.10 * 3.0 * TL3_{conc})$$

Solving for $TL3_{conc}$:

$$TL3_{conc} = 0.088\ mg\ MeHg/kg\ fish$$

$$TL4_{conc} = 0.088\ mg/kg * 3.0 = 0.26\ mg\ MeHg/kg\ fish$$

4.5.3.3 Bald Eagle Safe Tissue Levels

Calculation of methylmercury tissue levels for bald eagle is slightly more complicated because bald eagles consume omnivorous birds (OB), piscivorous birds (PB), and fish. The omnivorous birds of concern in the bald eagle diet feed on trophic level 2 aquatic prey (mostly invertebrates). To solve the equation, safe tissue concentrations in the other eagle prey types are expressed in terms of the lowest food chain level (TL2) common to all prey types (USFWS, 2004). To translate the TL2 concentration into the piscivorous bird safe level, staff used the food chain multiplier for TL3 small fish (FCM 3/2) and the food chain multiplier relating piscivorous birds and small TL3 fish (FCM PB). Like osprey, bald eagles tend to eat TL3 and TL4 fish of similar size, hence the use of the TL4/3 ratio.

$$TDSL_{bald\ eagle} = (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc}) + (\%diet_{OB} * OB_{conc}) + (\%diet_{PB} * PB_{conc})$$

Where:

$$TL3_{conc\ large\ fish} = TL2_{conc} * FCM\ 3/2$$

$$TL4_{conc\ large\ fish} = TL2_{conc} * FCM\ 3/2 * TL\ 4/3$$

$$OB_{conc} = TL2_{conc} * FCM\ OB$$

$$PB_{conc} = TL2_{conc} * FCM\ 3/2 * FCM\ PB$$

$$0.195\ mg/kg = (0.58 * 5.7 * TL2_{conc}) + (0.13 * 5.7 * 3.0 * TL2_{conc}) + (0.13 * 10 * TL2_{conc}) + (0.05 * 5.7 * 12.5 * TL2_{conc})$$

Solving for $TL2_{conc}$:

$$TL2_{conc} = 0.019\ mg\ MeHg/kg\ fish$$ *(not eaten by eagles; used to determine other safe levels)*

$$TL3_{conc\ large\ fish} = 0.019 * 5.7 = 0.11\ mg\ MeHg/kg\ fish$$

$$TL4_{conc\ large\ fish} = 0.019 * 5.7 * 3.0 = 0.31\ mg\ MeHg/kg\ fish$$

$$OB_{conc} = 0.019 * 10 = 0.19\ mg\ MeHg/kg\ omnivorous\ birds$$

$$PB_{conc} = 0.019 * 5.7 * 12.5 = 1.35\ mg\ MeHg/kg\ piscivorous\ birds$$

4.5.3.4 Peregrine Falcon Safe Tissue Levels

Peregrine falcons consume almost exclusively avian prey, some of which is aquatic-dependent. To solve for safe concentrations in omnivorous and piscivorous bird prey, these terms are expressed as functions of the lowest trophic level common to the birds' food web, which is TL2 aquatic prey (USFWS, 2004).

$$TDSL_{peregrine} = (\%diet_{OB} * OB_{conc}) + (\%diet_{PB} * PB_{conc})$$

Where:

$$OB_{conc} = TL2_{conc} * FCM\ OB$$

$$PB_{conc} = TL2_{conc} * FCM\ 3/2 * FCM\ PB$$

$$0.139\ mg/kg = (0.10 * 10 * TL2_{conc}) + (0.05 * 5.7 * 12.5 * TL2_{conc})$$

Solving for $TL2_{conc}$:

$TL2_{conc}$ = 0.030 mg MeHg/kg fish *(not eaten by peregrines; used to determine other safe levels)*

OB_{conc} = 0.030 * 10 = 0.30 mg MeHg/kg omnivorous birds

PB_{conc} = 0.030 * 5.7 * 12.5 = 2.2 mg MeHg/kg piscivorous birds

Note that the safe fish tissue levels in Table 4.3 are partially watershed-dependent and are specific to the Delta. The acceptable, average fish tissue concentrations for wildlife consuming from one trophic level will be consistent across different water bodies. This is because all of the parameters used to calculate the safe fish levels (species body weight, consumption rate and reference dose) were obtained from published literature and apply on a national or regional scale (Table 4.2). For species consuming fish from two trophic level classifications or piscivorous birds, translators (FCM or TLR) were used to calculate the safe concentrations in prey fish and piscivorous birds. These translators should be derived from site-specific data when possible and may differ between watersheds. For the Delta targets, the TLR and FCM between trophic level 4 and 3 fish were specific to the Delta. The FCMs for piscivorous birds, omnivorous birds and trophic level 3 fish were literature-derived average values.

Central Valley Water Board staff is not proposing safe tissue levels in piscivorous or omnivorous birds as TMDL targets. Data are lacking to compare safe levels in bird prey with existing conditions. By lowering methylmercury concentrations in fish and aquatic prey to safe levels shown in Table 4.3, staff anticipates that concentrations in birds feeding in the aquatic food web will decline to safe levels as well. In particular for peregrine falcon, the desired safe level in piscivorous birds is 2.2 mg/kg. Dividing the safe piscivorous bird level by 12.5 (FCM PB) results in a safe level in TL3 prey fish (150-350 mm length) of 0.17 mg/kg, which is above the proposed target for large TL3 fish.

Wildlife targets for TL3 and TL4 fish greater than 150 mm in length may be directly compared with targets developed to protect human consumers, as discussed in the following section. In Section 4.7, the wildlife and human targets that are trophic level and size-specific are incorporated into a single target based on largemouth bass that is protective of humans and all wildlife species of concern.

4.6 Human Health Targets

Numeric targets can be developed to protect humans in a manner analogous to targets for wildlife. A reference dose, average body weight and consumption rates are used along with Equations 4.1 and 4.3 to calculate safe fish tissue levels. In this section, the human health exposure parameters are discussed.

4.6.1 Acceptable Daily Intake Level

Central Valley Water Board staff used the USEPA RfD for methylmercury (USEPA, 2001) in Delta target calculations. The adverse effect level is based upon results of tests of neuropsychological function in children in the Faroe Islands exposed to methylmercury in fish. The USEPA incorporated a composite uncertainty factor of 10 for a final RfD of 0.1 µg methylmercury/kg bwt/day (USEPA, 2001). The USEPA describes its RfD as an estimate of a daily exposure level to humans that is likely to be without an appreciable risk of deleterious effect during a lifetime. The USEPA RfD is applied to the general population.[17]

4.6.2 Body Weight & Consumption Rate

This report uses the USEPA's standard adult bodyweight of 70 kg. Using an average pregnant female bodyweight (65 or 67 kg) would have very little difference on the calculation of mercury targets in fish.

Consumption rate is the most difficult of the fish tissue target variables to select because human consumption is variable. The amount of methylmercury ingested is highly dependent on the amount of fish and the sizes and species of fish consumed. The preferred level of Delta fish consumption is bounded by the limited amount recommended in the existing fish advisory and the rate of a very high consumer. People could eat unlimited quantities of Delta fish if the fish mercury concentration was zero. Human health is best protected by both cleanup and education. Education is needed until the effects of mercury reduction are seen in fish tissue levels. During the TMDL implementation period, consumers should be encouraged to eat smaller fish and species with lower mercury concentrations.

A comprehensive survey of consumption of Delta fish has not been conducted. Thus, staff examined San Francisco Bay and national fish consumption studies, as well as several localized and pilot studies in the Delta, to develop Delta-specific consumption scenarios and ultimately recommend targets for human protection.

The USEPA recommends default consumption rates for the general population and some subpopulations (USEPA, 2000a). Default consumption rates are derived from data collected nationwide as part of the 1994-96 USDA Continuing Survey of Food Intake by Individuals

---

[17] "In the studies so far published on subtle neuropsychological effects in children, there has been no definitive separation of prenatal and postnatal exposure that would permit dose-response modeling. That is, there are currently no data that would support the derivation of a child (versus general population) RfD. This RfD is applicable to the lifetime daily exposure for all populations, including sensitive subgroups. It is not a developmental RfD per se, and its use is not restricted to pregnancy or developmental periods" *Water Quality Criterion for Methylmercury, Section 4-6* (USEPA, 2001).

(CFSII). The USEPA reports rates separately for consumption of freshwater and marine fish. The USEPA recommends a fish intake rate of 17.5 g/day (about one 8-ounce uncooked fish meal every two weeks[18]) to protect the general population consuming freshwater and estuarine fish. This value represents the 90th percentile consumption rate for all survey participants, including those who do not eat fish. In selecting the 90th percentile, rather than the mean or median, the USEPA intended to recommend a consumption rate that is protective of the majority of the entire population. The USEPA recommended a consumption rate of 142.4 g/day (four to five 8-ounce, uncooked, portions per week) of local fish to represent anglers who use locally caught fish as a main source of protein. This value represents the 99th percentile consumption rate for all survey participants.

A detailed survey of consumption by anglers in San Francisco Bay was conducted in 1998 and 1999 (SFEI, 2000). The consumption rates for the 90th and 95th percentiles of anglers that were "consumers" (consumed Bay fish at least once prior to the interview) were 16 and 32 g/day, respectively. The San Francisco Bay Mercury TMDL selected the consumption rate for the 95th percentile of anglers (32 g/day) for calculation of the San Francisco Bay fish mercury target (0.2 mg/kg) to protect people who choose to eat San Francisco Bay fish on a regular basis (Johnson and Looker, 2004; SFBRWQCB, 2006).

California Department of Public Health staff interviewed members of sub-populations thought to have high consumption rates (CDHS, 2004) and conducted several pilot fish consumption surveys in the Delta (CDHS, 2005 and 2006; Ujihara, 2006). From the interviews, CDPH learned that being able to safely eat Delta fish is important to many people. Members of all races and many ethnic groups fish in the Delta. Preferences for angling location, language spoken, and fish species consumed are important for developing education and outreach programs.

The CDPH conducted small surveys of anglers in three parts of the Delta (CDHS, 2005 and 2006; Ujihara, 2006). Of boaters docking in Contra Costa County surveyed in 2005, 50% reported never eating Delta fish; 3% ate it more than once per week. Of boat and shore anglers on the Sacramento River between Rio Vista and the American River interviewed during salmon season in 2003, 17% ate Delta fish more than once per week. Shore anglers at two southern Delta and two San Joaquin River sites outside the Delta were interviewed in October/November 2005. Of the total respondents who ate any fish in the 30-day period prior to the survey, the geometric mean consumption rates were 22, 17, and 27 grams uncooked fish per day for locally caught, commercial, and total fish, respectively; these rates are less than one 8-ounce meal per week. Anglers were typically male. Many respondents in the Sacramento River and Delta/San Joaquin River angler surveys said that women and children in their households eat Delta fish.

A recent fish consumption and advisory awareness survey of low-income women at a WIC[19] clinic in Stockton found that 32% of the 500 survey participants ate Delta fish and 95% ate

[18] Although the target calculations use bodyweights and consumption rates for adult humans, the resulting fish tissue levels protect children as well. Children's bodyweights and smaller portion sizes can also be fitted into Equations 4.1 and 4.3. The OEHHA has published a table of sizes of typical meals of fish that correspond to smaller bodyweights (OEHHA, 1999). Children would only be at risk of mercury toxicity if they consumed more than the average portion for their body size.

[19] Special Supplemental Nutrition program for Women, Infants, and Children (WIC).

commercial fish (Silver *et al*., 2007). For participants who ate any fish in the 30-day period prior to the survey, the geometric mean consumption rates equaled 13, 33, and 35 grams uncooked fish per day for Delta, commercial, and total fish, respectively.[20] Cambodian, Asian/Pacific Islander, and African American participants had the highest mean consumption rates (24, 22, and 18 grams uncooked fish per day, respectively).

In 2005-2007, researchers from University of California Davis interviewed anglers and community members in the North Delta region about eating fish (Shilling *et al.,* 2008). The study area included the Sacramento River between Rio Vista and the American River and the Sacramento Deep Water Ship Channel. The average rate of consumption of locally caught fish was about 39 g/day uncooked fish/day. Women and men ate fish at similar rates. Average consumption rates of locally caught fish were highest for Hispanic and Lao participants. The authors plan to conduct more interviews in 2008.

4.6.3 Consumption of Fish from Various Trophic Levels & Sources

Species and size of fish as well as consumption rate affect methylmercury intake. It is difficult to estimate amounts of various species of sport fish that might be consumed from the Delta. Based on the CSFII national survey, the USEPA assumed that humans eat freshwater and estuarine fish from trophic levels two (3.8 g/day), three (8.0 g/day) and four (5.7 g/day) (USEPA, 2001). These rates are 21.7, 45.7, and 32.6% of the total 17.5 g/day, respectively. Trophic level 2 species, such as clams, crayfish, shrimp and shimofuri goby, are harvested from the Delta for human consumption (Appendix C). However, CDFG creel surveys (CDFG, 2000-2001) and anecdotal information provided by CDFG staff (Schroyer, 2003) indicate that many Delta anglers do not take home TL2 species. As described in Figure C.1 in Appendix C, the creel surveys indicate that Delta anglers may target an almost even mix of TL3 (American shad, salmon, sunfish, splittail) and TL4 (catfish and striped bass) fish in the Sacramento and Mokelumne Rivers subareas of the Delta, and primarily TL4 species (striped bass and catfish) throughout the rest of the Delta. Anecdotal information provided by CDFG staff (Schroyer, 2003) indicates that even in the rest of the Delta, many anglers take home a mix of TL3 and TL4 fish species. In the Delta consumption surveys described in previous paragraphs, anglers reported taking home catfish, striped bass, carp, bluegill, salmon, largemouth bass, crappie, sturgeon, and crayfish (CDHS, 2005 and 2006; Ujihara, 2006).

When evaluating potential fish tissue targets, staff considered five different tropic level distributions of locally caught fish (Table 4.5). Staff considered the TL2/3/4 mixture used by the USEPA for one distribution and Delta-specific information to develop four other distributions: 100% TL4, even mix of TL3 and 4, and an even mix of TL3 and 4 with small amounts of TL2 species (e.g., clams and shrimp).

When determining safe levels of Delta fish consumption, staff also considered the intake of methylmercury from commercial fish (see definition of RSC in Section 4.4). Many fish consumers eat a combination of locally caught and commercially bought fish. Based on the

[20] This study reported consumption in grams of cooked fish. In order to compare the studies, Central Valley Water Board staff converted units of cooked fish to uncooked fish by multiplying by 1.25.

national CFSII survey, the USEPA assumes an average consumption rate of commercial fish of 12.46 g/day, which results in an average daily intake of 0.027 μg methylmercury/kg bwt-day (USEPA, 2001). For people eating fish from commercial markets and the Delta, the safe intake level of methylmercury from Delta fish is the reference dose minus the methylmercury from commercial fish (0.1 μg/kg-day minus 0.027 μg/kg-day equals 0.073 μg/kg-day).[21]

4.6.4 Safe Rates of Consumption of Delta Fish

The USEPA issued a recommended criterion of 0.3 mg/kg methylmercury in locally caught fish consumed by humans (USEPA, 2001)[22]. The USEPA human health criterion was calculated using a default consumption rate of freshwater/estuarine fish of 17.5 g/day (about one meal every two weeks) and commercial (marine) fish of 12.46 g/day. The criterion assumed that humans eat freshwater and estuarine fish from TL2 (21.7%), TL3 (45.7%) and TL4 (32.6%). However, the USEPA's Water Quality Criterion report noted that the criterion can be adjusted on a site-specific basis to reflect regional or local consumption patterns and/or specific populations of concern. These include the consumption rates of local fish and the RSC estimate. For example, the San Francisco Bay mercury fish tissue objective of 0.2 mg/kg was calculated using a consumption rate of 32 g/day (about one meal per week) derived from a San Francisco Bay consumption survey. The San Francisco Bay objective is applied to the average mercury concentration in the five most commonly consumed Bay fish species: striped bass, California halibut, jacksmelt, white sturgeon, and white croaker (three TL4 species and two TL3 fish species; SFBRWQCB, 2006).

In the absence of Delta-specific consumption rates, the USEPA default consumption rate (17.5 g/day), San Francisco Bay consumption rate (32 g/day), and USEPA recommended consumption rate for anglers whose main source of protein is from locally caught fish (142.4 g/day) were used in Equation 4.1 to estimate the safe methylmercury level in the total diet for humans consuming Delta fish (Table 4.5). In addition, scenarios were developed for anglers who consume Delta and commercial fish, and for anglers who consume only Delta fish. For each of the total diet safe levels associated with the different consumption rates, different distributions of locally caught fish were considered. Because some Delta consumers eat TL2 species, two scenarios assume Delta consumers eat small proportions of TL2 species.

Equation 4.3 was used to develop safe levels for each trophic level of Delta fish. In order to solve Equation 4.3 for the desired concentrations in TL2, TL3 and TL4 biota, concentrations in the higher trophic levels are put in terms of the concentration in the lowest trophic level. Equation 4.3 is then rearranged to solve for the lowest trophic level concentration. In order to express the concentration in a higher trophic level, trophic level ratios were used. The TLRs used in the calculation of Delta human targets are shown in Table 4.6. Existing Delta fish

[21] Most commercial fish do not come from the Delta. The most popular fish and seafood bought in commercial markets are marine species such as scallops, shrimp, and tuna. The average consumption rate of marine fish reported by all respondents in the national CFSII survey was 12.46 g/day (three meals every two months; USEPA, 2001). The average concentration of methylmercury in commercial species weighted by frequency of consumption is 0.16 mg/kg (USEPA, 2001)

[22] The USEPA rounded from 0.288 mg/kg to 0.3 mg/kg for use as its recommended methylmercury criterion. Central Valley Water Board staff's calculations throughout the rest of this report are rounded to two decimal places, e.g., 0.29 mg/kg.

concentration data were used to develop the ratios. The following example illustrates how the trophic level fish targets were developed for Scenario A.1 in Table 4.5 using Equations 4.1 and 4.3.

Per Equation 4.1:

$$\text{Safe MeHg in total diet of Delta fish} = \frac{\text{(Human RfD - Relative source contribution) * Body weight}}{\text{Consumption rate}}$$

$$0.29 \text{ mg/kg} = \frac{0.073\ \mu\text{g MeHg/kg-day} * 70 \text{ kg}}{17.5 \text{ g/day}}$$

Per Equation 4.3:

$$0.29 \text{ mg/kg} = (\%\ dietTL_2 * TL3_{conc}) + (\%\ dietTL_3 * TL3_{conc}) + (\%\ dietTL_4 * TL4_{conc})$$

Where: $TL3_{conc} = TL2_{conc} * TLR\ 3/2$

$TL4_{conc} = TL2_{conc} * TLR\ 3/2 * TLR\ 4/3$

$$0.29 \text{ mg/kg} = (21\% * TL2_{conc}) + (46\% * TL2_{conc} * 4.5) + (33\% * TL2_{conc} * 4.5 * 2.9)$$

Solving for $TL2_{conc}$:

$TL2_{conc}$ = 0.30 / (0.21 + (0.45*4.5) +(0.33*4.5*2.9)) = 0.046 mg/kg in shrimp & clams

$TL3_{conc}$ = 0.046 mg/kg * 4.5 = 0.20 mg/kg in 150-500 mm fish

$TL4_{conc}$ = 0.046 mg/kg * 4.5 * 2.9 = 0.45 mg/kg in 150-500 mm fish

The highlighted safe levels for TL3 and TL4 fish in Scenarios A.1, A.4, B.4 and E.3 are evaluated as fish tissue objective alternatives in Chapter 3 of the draft Basin Plan Amendment staff report. As indicated by Table 4.5, potential safe levels of mercury in large Delta TL4 fish range from 0.05 to 0.80 mg/kg. Safe methylmercury concentrations can be higher when consumers of Delta fish do not eat commercial fish. However, in interviews of local community based groups and pilot surveys, most respondents who eat Delta fish consume commercial fish as well (CDHS, 2004; Silver 2007; and Ujihara, 2006). Staff therefore narrowed the options for further consideration by assuming Delta fish consumers eat commercial fish unless consumers are highly dependent on Delta fish (Scenario E).

Including small amounts of TL2 species into the diet distribution (Scenarios A.2, A.3, B.2, and B.3) makes little difference in the safe methylmercury concentrations in TL3 and TL4 fish, relative to an even mix of just TL3 and TL4 fish. To protect the many Delta anglers who likely do not eat TL2 species, staff proceeded with consideration of TL3 and 4 fish only.

To further assess the feasibility of attaining the targets, staff compared them to regional background conditions defined by a recent study by the USEPA and Oregon State University (Peterson *et al.*, 2007). This study included the collection and analysis of 2,707 large TL3 and TL4 fish from 626 streams and river segments in the western United States, including California, using a probability design. The purpose of the study was to assess the distribution of mercury in fish across the western United States. Central Valley Water Board staff evaluated the study results in terms of the existing fish mercury levels in the Delta and alternative fish tissue targets (Foe, 2007).

Only about 1 to 3% of the waterways evaluated by the regional study had fish mercury concentrations higher than those observed in the Mokelumne/Cosumnes subarea of the Delta. Likewise, fish mercury concentrations in the Sacramento, San Joaquin, and Yolo Bypass subareas were in the top 20 to 25% of fish mercury concentrations observed throughout the western United States. This confirms that Delta fish have elevated concentrations in comparison to regional background levels and suggests that the Delta and its tributary watersheds contain mercury sources in addition to atmospheric deposition, e.g., abandoned mines and sites where the mercury is efficiently converted to methylmercury that bioaccumulates in the aquatic food web (Foe, 2007). Of the sampled waterways in the western United States, none supported a fish population with mercury concentrations as low as Scenario E.3 (0.05 mg/kg in large TL4 fish) (Peterson *et al.*, 2007; Foe, 2007). Therefore, this target may not be attainable. In contrast, about 30% to 40% of the sampled waterways supported a fish population with mercury concentrations lower than Scenarios A.1, A.4, and B.4, suggesting that these scenarios may be attainable with implementation of a vigorous control program.

As discussed in the draft Basin Plan Amendment staff report, the TL3 and TL4 targets produced by Scenario B.4 of 0.08 mg/kg and 0.24 mg/kg, respectively, are recommended by Central Valley Water Board staff for the protection of humans for several reasons:

- They fully protect wildlife species consume large fish, including threatened and endangered species as required by the Endangered Species Act.
- They reasonably protect people who eat Delta fish by safely allowing the consumption of one eight-ounce meal per week of Delta fish, a consumption rate greater than the USEPA default rate used in Scenarios A and C. These objectives are therefore more protective of people who by custom, need, or enjoyment, more frequently eat Delta fish.
- They incorporate local consumption patterns, which show that Delta anglers commonly target fish like salmon (TL3) and striped bass (TL4).
- They are consistent with the fish tissue objectives approved by the State Water Board for San Francisco Bay (SFBRWQCB, 2006; SWRCB, 2007). Like the Scenario B.4 targets, the methylmercury objective recommended for the Bay is based on protecting people who eat 32 g/day of local fish. Scenario B.4 takes into consideration that people, fish-eating wildlife and their prey (e.g., anadromous species) travel between the Delta and San Francisco Bay.
- They are attainable because they are not less than background fish mercury levels in the western United States and they can be reliably measured (given current analytical methods for water and fish; see Section 5.2 in Chapter 5).

These targets are carried forward throughout the rest of this report for use in the food web evaluation, linkage analysis and development of methylmercury source allocations.

Table 4.5: Safe Concentrations of Methylmercury in Delta Fish by Trophic Level (TL) to Protect Humans Calculated Using Varying Assumptions about Consumption Rates and Trophic Level Distribution.

Scenario	Body Weight (kg)	Acceptable Daily Delta Fish MeHg Intake Level (µg/kg-day) [a]	Total Consumption Rate of Delta Fish (g/day) [b]	Safe MeHg Level in Total Diet of Delta Fish (mg/kg) [c]	Distribution of Locally Caught Fish by TL			Safe Concentration of MeHg in Fish by TL (mg/kg) [d]		
					TL2	TL3	TL4	TL2	TL3	TL4
For people eating commercial and Delta fish:										
A.1	70	0.073	17.5	0.29	21.7%	45.7%	32.6%	0.04	**0.20**	**0.58**
A.2					10%	45%	45%	0.04	0.16	0.47
A.3					5.0%	47.5%	47.5%	0.03	0.16	0.45
A.4					---	50%	50%		0.15	0.43
A.5					---	---	100%			**0.29**
B.1	70	0.073	32	0.16	21.7%	45.7%	32.6%	0.02	0.11	0.32
B.2					10%	45%	45%	0.02	0.09	0.26
B.3					5.0%	47.5%	47.5%	0.02	0.09	0.25
B.4					---	50%	50%		**0.08**	**0.24**
B.5					---	---	100%			0.16
For people eating only Delta fish:										
C.1	70	0.1	17.5	0.40	21.7%	45.7%	32.6%	0.06	0.28	0.80
C.2					---	50%	50%		0.21	0.59
C.3					---	---	100%			0.40
D.1	70	0.1	32	0.22	21.7%	45.7%	32.6%	0.03	0.15	0.44
D.2					---	50%	50%		0.11	0.33
D.3					---	---	100%			0.22
E.1	70	0.1	142.4	0.05	21.7%	45.7%	32.6%	0.01	0.03	0.10
E.2					---	50%	50%		0.03	0.07
E.3					---	---	100%			**0.05**

(a) For people eating fish from commercial markets and the Delta, the safe intake level of methylmercury from Delta fish is the USEPA reference dose minus the methylmercury from commercial fish (0.1 µg/kg-day minus 0.027 µg/kg-day = 0.073 µg/kg-day). Scenarios C through E assume no commercial fish are consumed.

(b) The USEPA human health criterion was calculated using a default consumption rate of freshwater/estuarine fish of 17.5 g/day and of commercial (marine) fish of 12.46 g/day, as derived from national dietary surveys (USEPA, 2001). The criterion assumed that humans eat freshwater and estuarine fish from TL2 (21.7%), TL3 (45.7%) and TL4 (32.6%).

(c) The USEPA criterion calculations yielded a methylmercury value of 0.288 mg methylmercury/kg fish, which the USEPA rounded to one significant digit. The Region 2 San Francisco Bay Mercury TMDL target calculations yielded a methylmercury value of 0.16 mg methylmercury/kg fish, which Region 2 also rounded to one significant digit in the San Francisco Bay Mercury TMDL report (Johnson and Looker, 2004).

(d) Values were calculated using Equation 4.3 and trophic level ratios presented in Table 4.6. Values were rounded to two decimal places. The highlighted targets (Scenarios A.1, A.4, B.4 and E.3) are evaluated as fish tissue objective alternatives in the draft Basin Plan Amendment staff report. The TL3 and TL4 targets produced by Scenario B.4 are recommended for the protection of humans that consume fish from throughout the Delta and are carried forward throughout the rest of this report for use in the linkage analysis and development of allocations.

Table 4.6: Trophic Level Ratios for Delta Human Target Development

Translator	Value	Source
TLR 4/3	2.9	Ratio between existing MeHg concentrations in large TL4 fish (150 mm [or legal catch limit] to 500 mm length) and large TL3 fish (150 mm [or legal catch limit] to 500 mm length). Calculated from Delta-wide average fish tissue levels; see Appendix B.
TLR 3/2	4.5	Ratio between existing MeHg concentrations in large TL3 fish (150-500 mm length) and TL2 species potentially consumed by humans (shrimp and clams). Calculated from Delta-wide average fish tissue levels; see Appendices B, C and K.

4.7 Trophic Level Food Group Evaluation

As noted in the previous section, Central Valley Water Board staff recommends targets of 0.08 and 0.24 mg/kg in large TL3 and TL4 fish, respectively, for the protection of humans that consume fish from throughout the Delta. In this section, the relationships between methylmercury concentrations in large TL4 fish and the other trophic level food groups are examined. The purpose of this analysis is to determine whether consistent relationships might exist between the assemblages of fish and, if so, whether it might be possible to describe safe mercury ingestion rates for humans and wildlife species in terms of large TL4 fish. This analysis enables staff to determine whether a water quality objective based on methylmercury in large fish developed for the protection of humans may or may not be protective of wildlife species that consume smaller or lower trophic level fish.

4.7.1 Data Used in Trophic Level Food Group Evaluation

Mercury concentrations for each trophic level food group sampled in the Delta are presented in Appendix K and summarized in Table 4.7. Values presented are average concentrations, weighted by the number of individual fish in composite samples. The trophic level food group concentrations are the result of analyzing 1,048 composite samples of 4,578 fish from 23 species in the Delta (Table B.2 and B.3 in Appendix B and Appendix K). Figure 4.1 illustrates the fish sampling locations used in the trophic level food group evaluation. The sampling was conducted by CDFG, SFEI, University of California, Davis, the Toxic Substances Monitoring Program, and the Sacramento River Watershed Program (Davis *et al.*, 2000; Davis *et al*., 2003; Slotton *et al.*, 2003; LWA, 2003; SWRCB-DWQ, 2002).

The data for each food group were assembled after considering four general rules. First, the data were restricted to samples collected between 1998 and 2001, the period with the most comprehensive sampling across the Delta. Second, migratory species (salmon, American shad, steelhead, sturgeon, striped bass) were excluded. These species likely do not reside year-round at the locations in the Delta where they were caught and their tissue mercury levels may not show a positive relationship with the mercury levels in resident animals. In addition, data for migratory species are not available for all Delta subareas, precluding an analysis to determine whether such a relationship might exist. A review of data available for several commercial species (striped bass, salmon, blackfish and crayfish) is provided in Appendix C.[23] Third, fish samples with lengths greater than 500 mm were not included. Data for fish larger than 500 mm are available for only some subareas. Capping the size at 500 mm allows comparable data for all Delta subareas. Finally, only fish fillet data were used in the human and eagle trophic level food group analysis. Humans typically consume fish fillets, while wildlife species, including eagles, eat whole fish. However, all the data for large fish typically consumed by eagles and other large wildlife species are from fillet samples, making it necessary to use fillet information for these species.[24] Whole fish data were used for the smaller wildlife species food groups.

Of the eight Delta subareas identified in Section 2.2.2 and Figure 2.2, three of the subareas were not included in the trophic level food group evaluation due to inadequate information. No fish were sampled from the Marsh Creek subarea between 1998 and 2001. In addition, small fish were sampled throughout the Yolo Bypass-South subarea between 1998 and 2001, but large fish were sampled only in the southernmost area; hence, the mercury levels in the trophic level food groups are not geospatially comparable. The only fish sampling conducted in the Yolo Bypass-North subarea took place in Greens Lake, which is not considered representative of the entire subarea. In addition, only large TL4 fish were sampled; no small fish were sampled.

Table 4.8 provides a comparison of the average mercury concentrations for each trophic level food group sampled in the Delta (Table 4.7) to the recommended targets for the species with the lowest safe fish methylmercury levels within each trophic level food group. The comparison indicates that the recommended targets for wildlife protection are already met in the Central and West Delta subareas. In addition, the comparison indicates that greater reductions may be required to achieve the recommended target for large TL4 fish developed for human protection than for the recommended targets for smaller and lower trophic level fish developed for wildlife protection. The following section describes a more direct method for comparing the level of protection provided by the different trophic level food group targets.

4.7.2 Trophic Level Food Group Comparisons

Regressions between methylmercury concentrations in large TL4 fish and the other TL food groups are presented in Figure 4.2. The relationships were evaluated using linear, exponential, logarithmic, and power curves; in each case the type of curve that provided the highest R^2 value was selected. All of the correlations were statistically significant ($P<0.05$ or less). The regressions demonstrate that there are predictable relationships between mercury concentrations in large TL4 fish and the other trophic level food groups in the Delta.

[23] Methylmercury concentrations in salmon and striped bass are important to human risk assessment because people frequently attempt to catch these two species. Average mercury concentrations in striped bass are similar to mercury levels in largemouth bass. The available mercury data for salmon indicate that their tissue concentrations are much lower that the mercury levels in bass (0.04 to 0.12 mg/kg). See Appendix C for more information about striped bass and salmon.

[24] Researchers in New York found that concentrations in whole body and muscle of large TL3 and TL4 fish were not significantly different (Becker and Bigham, 1995), suggesting that it is appropriate to use fillet data to evaluate exposure to wildlife species.

Table 4.9 presents the predicted safe dietary mercury concentrations for each target species in terms of large TL4 fish calculated from the regression equations in Figure 4.2. The recommended target of 0.24 mg/kg in large TL4 fish developed for the protection of humans is lower than the corresponding safe large TL4 fish mercury concentrations predicted for the other TL food groups, which ranged from 0.30 mg/kg for Western grebe to 1.12 mg/kg for Western snowy plover. This indicates that the recommended targets for large TL3 and TL4 fish developed for protection of humans are most likely protective of wildlife species that consume smaller or lower trophic level fish. In other words, reductions in methylmercury levels needed to achieve the recommended targets for large TL3 and TL4 fish are expected to produce reductions in smaller fish sufficient to fully protect wildlife species. To ensure that wildlife species dining only on small fish are protected, staff proposes an additional target of 0.03 mg/kg methylmercury in TL2 and 3 fish less than 50 mm in length. This target represents the safe level for prey consumed by the California least tern, a piscivorous species listed by the Federal government as endangered. As shown in Table 4.9, such a target for small fish also would protect the Western snowy plover.

Table 4.7: Mercury Concentrations in Trophic Level Food Groups Sampled in the Delta

Trophic Level Food Group	Hg Concentrations (mg/kg) by Delta Subarea [a]				
	Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
TL4 Fish (150-500 mm)	0.26	0.92	0.56	0.50	0.32
TL3 Fish (150-500 mm)	0.08	0.28	0.21	0.11	0.11
TL4 Fish (150-350 mm)	0.20	0.75	0.46	0.42	0.24
TL3 Fish (150-350 mm)	0.08	0.29	0.17	0.12	0.08
TL3 Fish (50-150 mm)	0.03	0.09	0.04	0.04	0.03
TL3 Fish (<50 mm)	0.02	0.07	0.03	0.04	0.03

(a) The trophic level food group mercury levels are weighted averages of mercury levels for resident fish within each food group collected in each Delta subarea between 1998 and 2001. These food groups correspond to the proposed numeric targets developed earlier in Chapter 4. Weighted average mercury concentration is based on the number of fish in the composite samples analyzed, rather than the number of samples.

Table 4.8: Percent Reductions in Fish Methylmercury Levels Needed to Meet Numeric Targets

Trophic Level Food Group	Target Species [a]	Target (mg/kg)	Delta Subareas				
			Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
TL4 Fish (150-500 mm)	Human	0.24	8%	74%	57%	52%	25%
TL3 Fish (150-500 mm)	Human	0.08	0%	71%	62%	27%	27%
TL4 Fish (150-350 mm)	Osprey	0.26	0%	65%	43%	38%	0%
TL3 Fish (150-350 mm)	Grebe	0.08	0%	72%	53%	33%	0%
TL3 Fish (50-150 mm)	Kingfisher	0.05	0%	44%	0%	0%	0%
TL3 Fish (<50 mm)	Least Tern	0.03	0%	57%	0%	25%	0%

(a) Only the recommended targets for the wildlife species with the lowest safe methylmercury concentrations in fish diet (Table 4.3) within each trophic level food group are evaluated. The proposed large TL3 and TL4 fish targets for human protection are lower than the targets proposed for protection of eagles.

Table 4.9: Predicted Safe Concentrations of Methylmercury in 150-500 mm TL4 Fish and Standard 350-mm Largemouth Bass Corresponding to Trophic Level Food Group (TLFG) Targets for the Protection of Piscivorous Species.

Trophic Level Food Group / Species	**TLFG Target** (mg/kg) [(a)]	**Predicted 150-500 mm TL4 Fish Safe Level** (mg/kg)	**Predicted Standard 350-mm Largemouth Bass Safe Level** (mg/kg) [(b)]
TL4 Fish (150-500 mm)			
Human	0.24	[(c)]	0.28
Bald eagle	0.31	[(c)]	0.36
TL3 Fish (150-500 mm)			
Human	0.08	0.24	0.24
Bald eagle	0.11	0.37	0.43
TL4 Fish (150-350 mm)			
Osprey	0.26	0.33	0.36
River otter	0.36	0.45	0.57
TL3 Fish (150-350 mm)			
Western grebe	0.08	0.30	0.31
Common merganser	0.09	0.35	0.38
Osprey	0.09	0.35	0.38
TL3 Fish (50-150 mm)			
Kingfisher	0.05	0.62	0.73
Mink	0.08	0.90	1.06
River otter	0.04	0.50	0.57
Double-crested cormorant	0.09	0.96	1.15
TL3 (<50 mm)			
California least tern	0.03	0.38	0.42
Western snowy plover	0.10	1.12	1.34

(a) The TLFG targets developed for bald eagle, osprey and river otter were developed using site-specific TLRs and/or FCMs combined with information provided in published literature. All other TLFG targets were entirely developed using information provided in published literature.

(b) The calculation and purpose of the standard 350-mm largemouth bass mercury concentrations are described in the following section (Section 4.8).

(c) The TL4 Goals are same as the TLFG Targets for human and eagle protection.

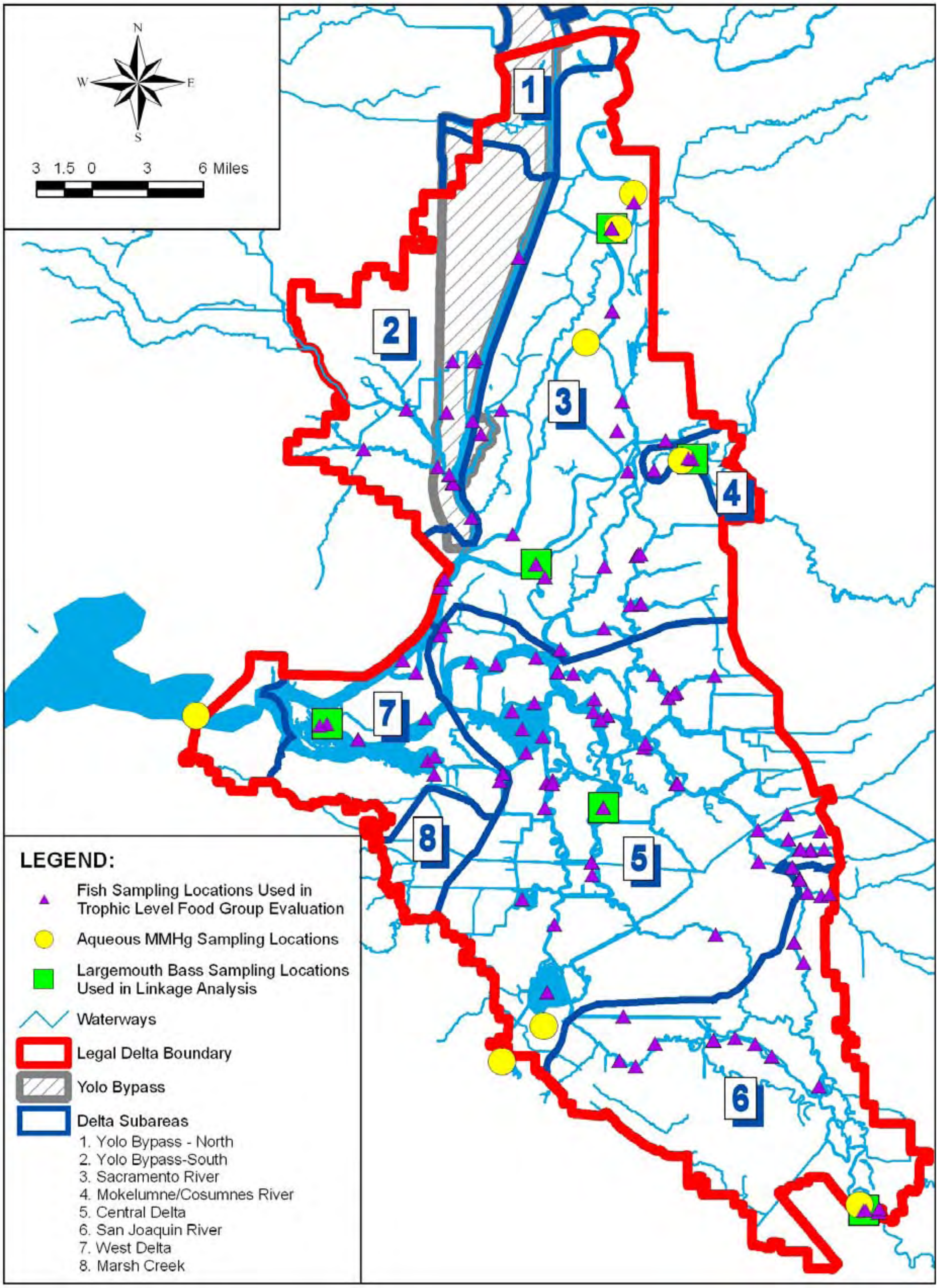

Figure 4.1: Fish and Water Sampling Locations Included in the Trophic Level Food Group and Largemouth Bass Evaluations.

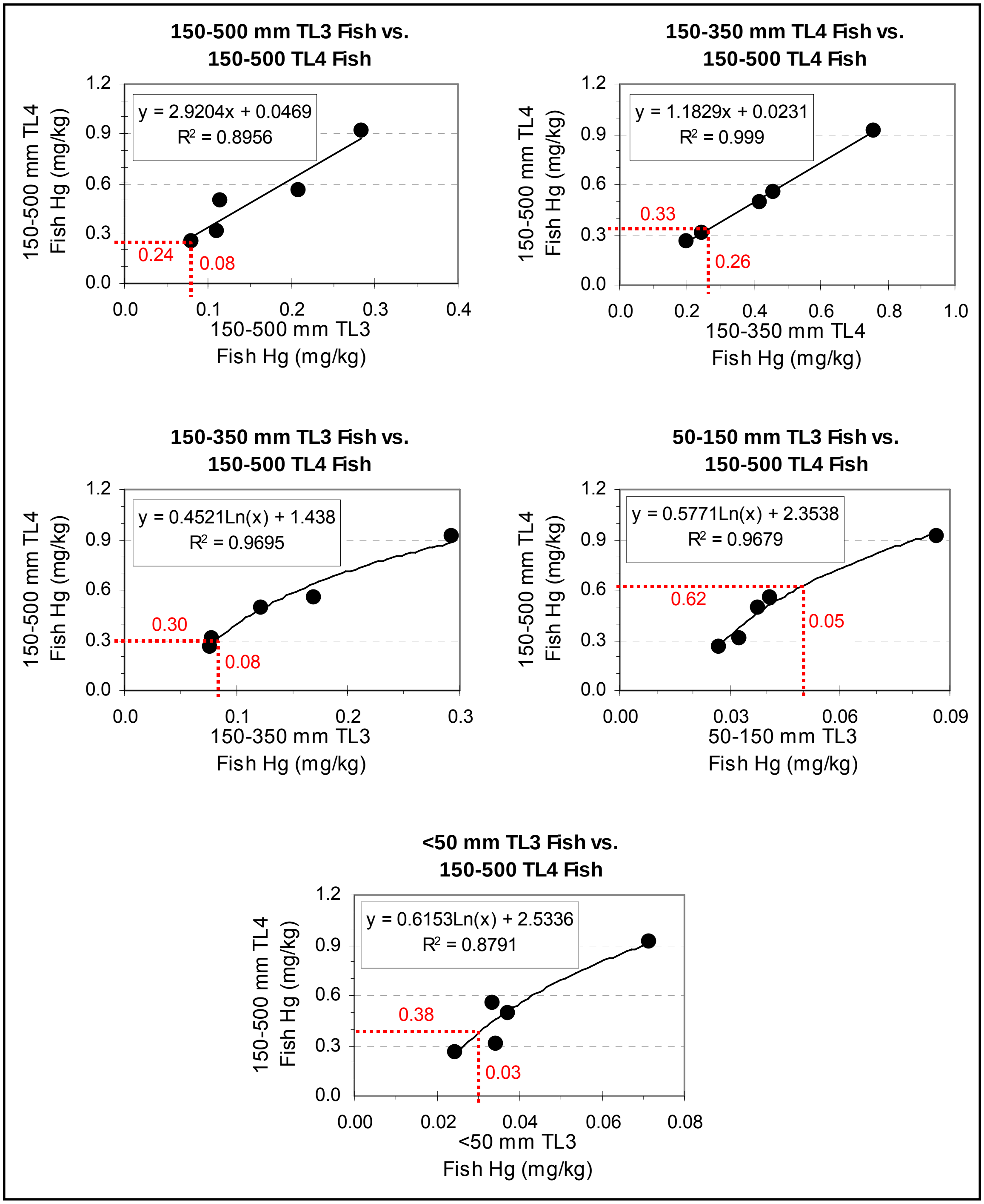

Figure 4.2: Comparison of Methylmercury Concentrations in Large (150-500 mm) TL4 Fish and Other Trophic Level (TL) Food Groups. The regressions are used to predict safe diets for target species listed in Table 4.9 in terms of large TL4 fish.

4.8 Largemouth Bass Evaluation

A goal of the TMDL is to link target methylmercury concentrations in fish to methylmercury concentrations in water to develop a goal for aqueous methylmercury that could then be used in development of an implementation plan. Chapter 5 (Linkage Analysis) describes the relationships between methylmercury in water and in largemouth bass in the Delta. Largemouth bass were selected for the linkage analysis for several reasons. Largemouth bass are a good bioindicator species. In addition, only largemouth bass data are available for the same sampling period and locations as the methylmercury water data (Figure 4.1). Largemouth bass, however, constitute only a portion of the diet of some of the human and wildlife consumers of Delta fish. The methylmercury targets determined above assume that humans and wildlife species consume a variety of sizes and species of fish from the Delta. In this section, the relationships between methylmercury concentrations in largemouth bass and the trophic level food groups were examined so that an implementation goal could be developed in terms of largemouth bass and, ultimately, linked to aqueous methylmercury.

Most of the information on mercury concentrations in the various trophic level food groups in the Delta was collected as species-specific composite samples between 1998 and 2001. Therefore, the largemouth bass evaluation was conducted in four parts. First, the methylmercury concentrations in largemouth bass of a standard size were estimated for each Delta subarea using the relationships between length and methylmercury tissue concentration[25] in samples collected in 2000. Second, correlations were run between standard 350-mm largemouth bass collected in 2000 and average concentrations of 300-400 mm largemouth bass (composite and individual samples) collected between 1998 and 2000. The year 2000 is significant because (1) aqueous methylmercury sampling began in March 2000 and (2) largemouth bass sampling adequate for the length/concentration regressions took place only in September/October 2000. The monthly March-October 2000 subset of the aqueous data has the greatest overlap with the lifespan of the largemouth bass sampled in September/October 2000. As these correlations were highly significant, the third step was to examine correlations between mercury concentrations in standard 350-mm largemouth bass and composites of all trophic level food groups collected in the Delta between 1998 and 2001. The purpose of this analysis was to determine whether consistent relationships might exist between the different assemblages of fish and, if so, whether it might be possible to describe safe mercury ingestion rates for humans and wildlife species in terms of the methylmercury concentration in a standard 350-mm largemouth bass. The final step was to determine a safe methylmercury concentration for each species in terms of the methylmercury concentration in 350-mm largemouth bass (Table 4.9).

---

[25] Determining the methylmercury concentration in a specific or "standard" size fish is a typical method of data analysis that allows comparison between sites and years. For largemouth bass from one site or subarea, mercury concentration is well correlated with length (Davis *et al*., 2003; data in Figure 4.3 in this report). This correlation is also useful in monitoring, as concentrations in fish in a range of lengths can be used to predict the concentration in a standard size. Hereafter, the mercury concentration in a "standard 350 mm largemouth bass" refers to the concentration obtained through a regression analysis as in Figure 4.3.

4.8.1 Largemouth Bass Standardization

The methylmercury content of a standard 350-mm length largemouth bass was determined at all sites where both water and fish tissue data were available (Figure 4.1) by regressing fish length against mercury body burden (Figure 4.3). Appendix K provides the concentration and length data for largemouth bass sampled in the Delta. Table 4.10 presents the predicted mercury values for 350 mm bass at each location where both water and fish tissue data were available. The predicted mercury concentration in standard 350 mm largemouth bass varied by a factor of five across the Delta (0.19 mg/kg in the Central Delta to 1.04 mg/kg in the Mokelumne River). Mercury concentration in a standard length 350 mm largemouth bass was selected because the length is near the middle of the size range collected at each site and therefore maximizes the predictive capability of the regression (Davis *et al*., 2003). Three hundred and fifty mm is slightly larger than CDFG's legal size limit of 305 mm (12 inches). A 350 mm bass is three to five years old (Schaffter, 1998; Moyle, 2002).

4.8.2 Correlations between Standard 350 mm and All Largemouth Bass Data

Figure 4.4 presents the regression between mercury levels in standard 350-mm largemouth bass collected in year 2000 and weighted-average concentrations in 300-400 mm largemouth bass collected between 1998 and 2000 in five delta subareas[26] (Table 4.10). Each data point represents one subarea. The correlation is statistically significant ($P<0.01$) and has a slope of 0.8, suggesting that mercury concentrations do not vary appreciably between the two groups. The results suggest that year 2000 standard 350-mm bass mercury levels are representative of mercury concentrations in largemouth bass collected between 1998 and 2000.

4.8.3 Largemouth Bass/Trophic Level Food Group Comparisons

Regressions between mercury concentrations in standard 350-mm largemouth bass and TL3 and TL4 food groups are presented in Figure 4.5. The purpose of this analysis was to determine whether consistent relationships might exist between the different assemblages of fish and, if so, whether it might be possible to describe safe mercury ingestion rates for wildlife species and humans in terms of the mercury concentration in a standard 350-mm largemouth bass. The relationships were evaluated using linear, exponential, logarithmic, and power curves; in each but one case the type of curve that provided the highest R^2 value was selected.[27] All of the correlations were statistically significant ($P<0.05$ or less). The regressions

[26] Data collected in 1998-2000 contained individual and composite samples. Mercury concentrations in the composite samples were weighted by number of individual fish in the composite and then averaged with individual results.

[27] A logarithmic curve best fits the points comparing standard 350-mm largemouth bass mercury concentrations to 150-500 mm TL4 fish (Figure 4.3). However, the curve intercepts the x-axis well above zero, preventing the prediction of standard largemouth bass mercury concentrations that corresponds to the range of alternative large TL4 fish mercury targets developed for human protection (0.58, 0.29, 0.24 and 0.05 mg/kg). This is also true of a linear curve: it intercepts the x-axis above zero. Therefore, a linear equation with the intercept set to zero was used to estimate standard 350-mm largemouth bass mercury concentrations that correspond to the preferred and alternative large TL4 fish targets. All three regressions are statistically significant ($P<0.01$). Use of either the linear or logarithmic curves to predict safe levels for largemouth bass that correspond to the TL4 target alternatives has additional uncertainty because two of the alternatives (0.24 and 0.05 mg/kg) are lower than the lowest of observed values (0.26 mg/kg in the Central Delta subarea) upon which the curves are based.

demonstrate that there are predictable relationships between mercury concentrations in standard 350-mm largemouth bass and all trophic level food groups in the Delta.

Table 4.9 presents the predicted safe dietary mercury concentrations for each TLFG target in terms of standard 350-mm bass. The safe largemouth bass mercury levels were calculated from the regression equations in Figure 4.5. The lowest largemouth bass mercury value (0.24 mg/kg) corresponds to 0.08 mg/kg in 150-500 mm TL3 fish. This is the most conservative of all the calculated largemouth bass safe levels and, if attained, should fully protect all listed beneficial uses in the Delta. Staff recommends that **0.24 mg/kg, wet weight, in a standard 350-mm largemouth bass** be used as an **implementation goal** in the linkage analysis (Chapter 5) and determination of methylmercury allocations (Chapter 8).

As described in Tables 4.8 and 4.11, percent reductions in fish methylmercury levels ranging between 0 and 77% will be needed to meet the recommended numeric targets for large and small TL3 and TL4 fish and the implementation goal for standard 350-mm largemouth bass in the different Delta subareas. Staff expects that when methylmercury concentrations in largemouth bass reach the recommended implementation goal for standard 350-mm largemouth bass, then concentrations in other aquatic organisms also will have declined sufficiently to protect human and wildlife consumers. Monitoring should be conducted in all trophic level food groups at that time to verify that the expected decreases have occurred.

Key points and options to consider for the numeric targets are listed after Figure 4.5.

Table 4.10: Mercury Concentrations in Standard 350-mm and 300-400 mm Largemouth Bass

	Hg Concentrations (mg/kg) by Delta Subarea				
	Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
Year 2000 Standard 350-mm largemouth bass collected in September/October 2000 (a)	0.19	1.04	0.72	0.68	0.31
300-400 mm largemouth bass collected between 1998 and 2000 (b)	0.31	0.94	0.76	0.64	0.30

(a) The standard 350-mm largemouth bass mercury concentrations are predicted values derived using the regressions in Figure 4.3.
(b) The values for the 300-400 mm bass are weighted-average concentrations in 300-400 mm largemouth bass collected between 1998 and 2000 from multiple locations within each of the five delta subareas.

Table 4.11: Percent Reductions in Standard 350-mm Largemouth Bass Methylmercury Levels Needed to Meet the Recommended Implementation Goal of 0.24 mg/kg in Each Delta Subarea.

Central Delta	Mokelumne River	Sacramento River	San Joaquin River	West Delta
0%	77%	67%	65%	23%

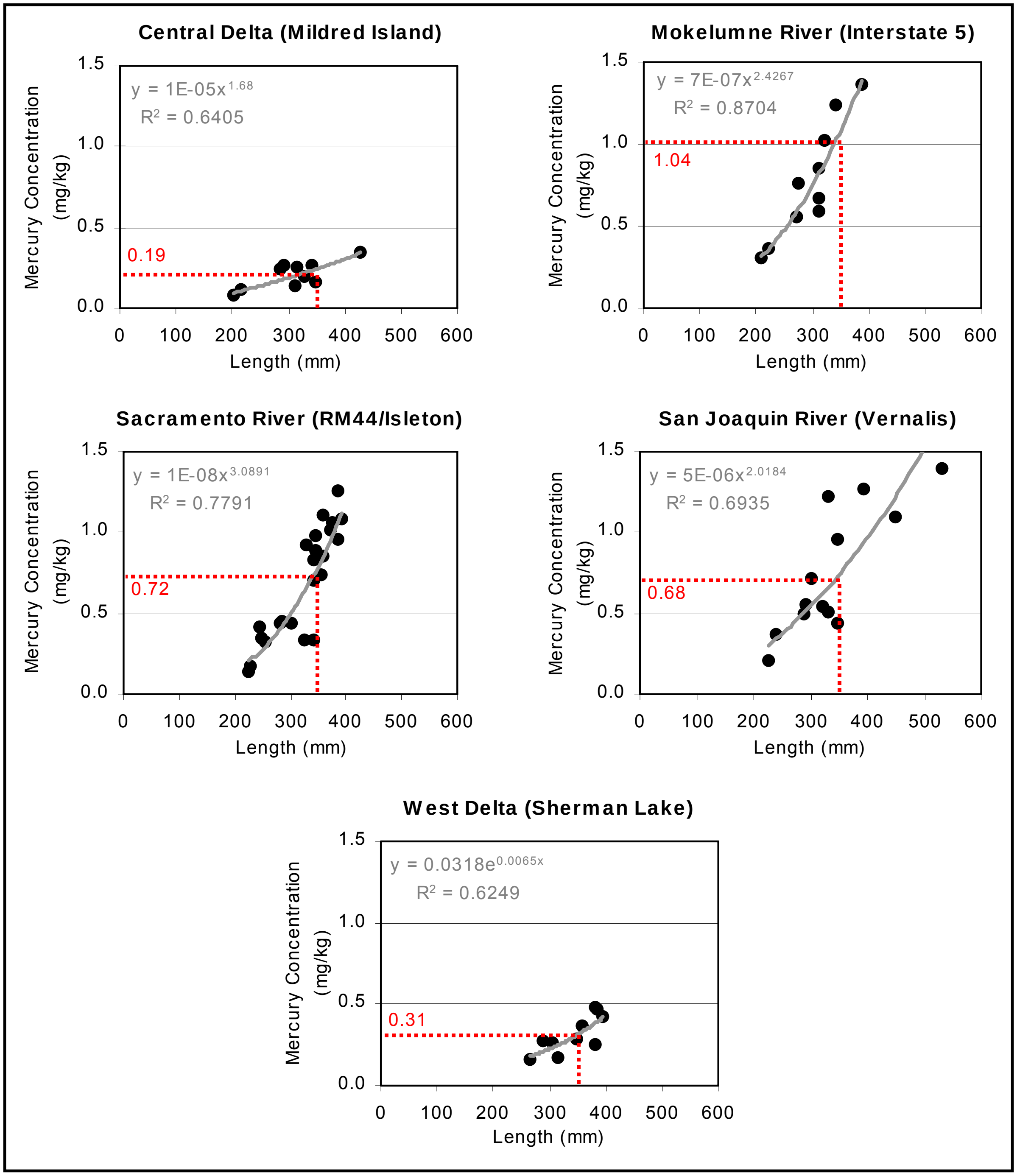

Figure 4.3: Site-specific Relationship between Largemouth Bass Length and Mercury Concentrations in the Delta. The relationships were used to predict the mercury content of a standard, 350-mm length bass sampled in September/October 2000, as indicated by the dashed lines. All relationships were significant at least at P<0.05.

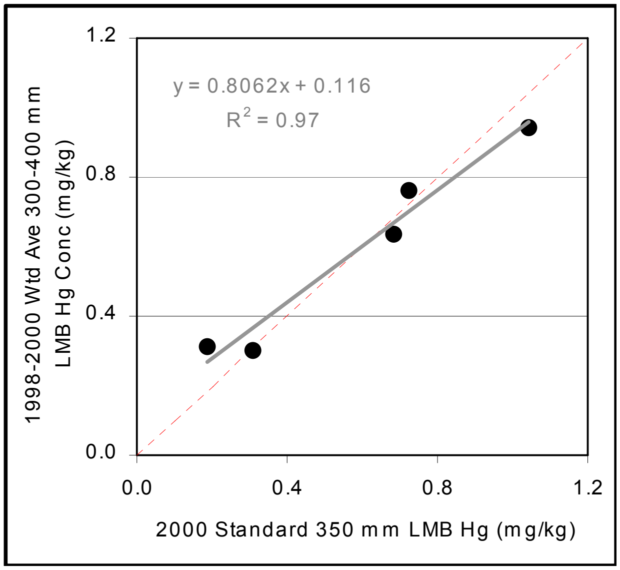

Figure 4.4: Comparison of Mercury Levels in Standard 350 mm Largemouth Bass (LMB) Collected at Linkage Sites in 2000 and Mercury Levels in 300-400 mm LMB Collected throughout Each Subarea in 1998-2000.

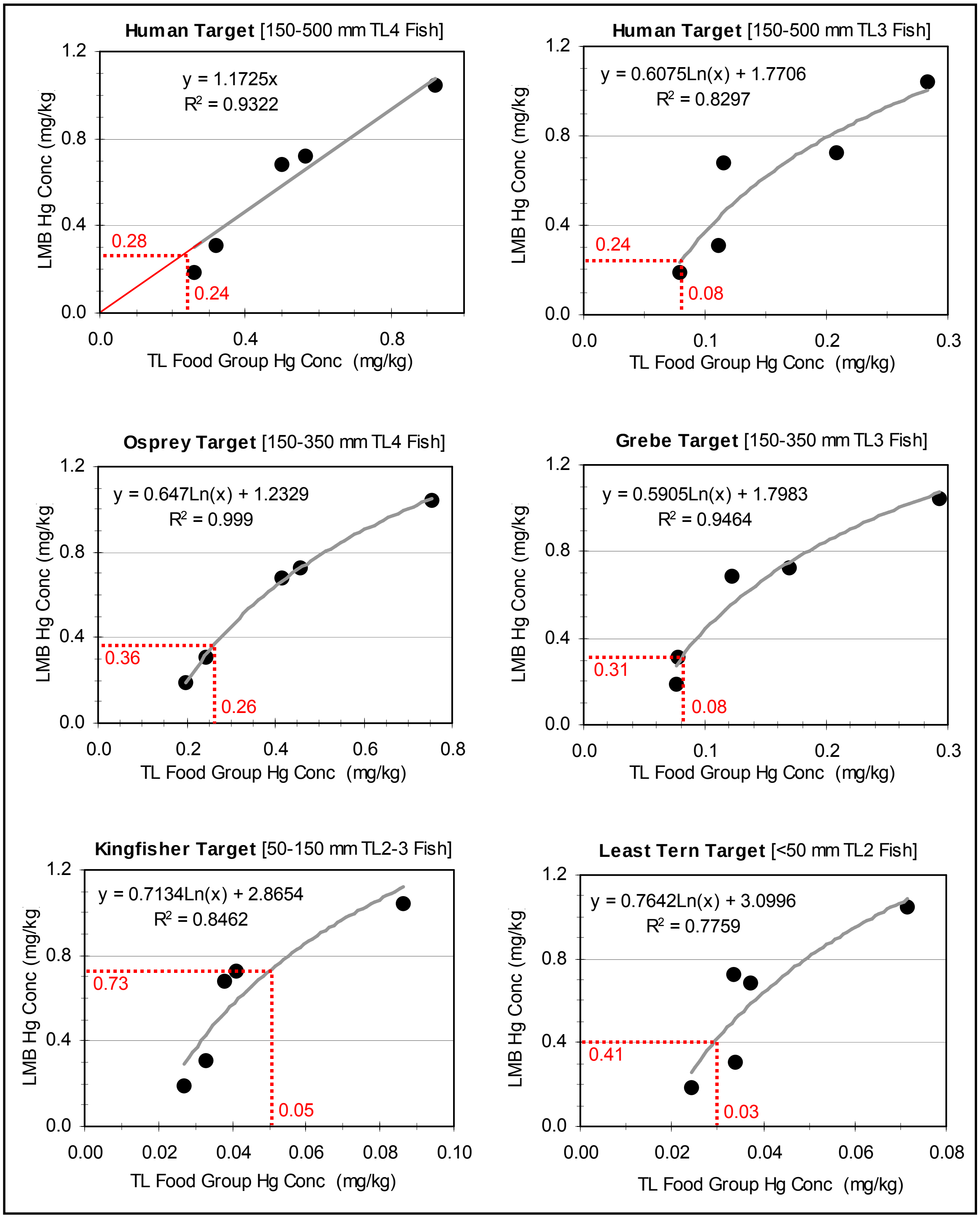

Figure 4.5: Comparison of Mercury Concentrations in Standard 350-mm Largemouth Bass (LMB) Caught in September/October 2000 and Composites of Fish from Various Trophic Level (TL) Food Groups Caught between 1998 and 2001.
The regressions are used to predict safe diets for target species listed in Table 4.9 in terms of largemouth bass mercury concentrations. Note, the recommended target for large TL4 fish (0.24 mg/kg) developed for human protection is lower than average mercury levels observed in the Delta, resulting in a corresponding standard 350-mm largemouth bass concentration that falls slightly below the regression curve based on observed values.

Key Points

- The concentration of methylmercury in fish tissue is the numeric target selected for the Delta methylmercury TMDL. Measurements of mercury in fish should be able to assess whether beneficial uses are being met because fish-eating (piscivorous) birds and mammals are most likely at risk for mercury toxicity.
- Piscivorous species identified in the Delta are: American mink, river otter, bald eagle, kingfisher, osprey, western grebe, common merganser, peregrine falcon, double crested cormorant, California least tern, and western snowy plover. Bald eagles, California least terns and peregrine falcons are listed by the State of California or by USFWS as either threatened or endangered species.
- Acceptable fish tissue levels of mercury for the trophic level food groups consumed by each wildlife species were calculated using the method developed by USFWS that addresses daily intake levels, body weights and consumption rates. Numeric targets were developed to protect humans in a manner analogous to targets for wildlife using USEPA-approved methods and regional information.
- Central Valley Water Board staff recommends two numeric targets for large fish: 0.24 mg/kg (wet weight) in muscle tissue of large trophic level four (TL4) fish such as bass and catfish and 0.08 mg/kg (wet weight) in muscle tissue of large TL3 fish such as carp and salmon. These targets are protective of (a) humans eating 32 g/day (1 meal/week) of commonly consumed, large fish; and (b) all wildlife species that consume large fish. The evaluation of the relationships between methylmercury concentrations in large TL4 fish and the other trophic level food groups indicated that wildlife species that consume smaller or lower trophic level fish would be protected by the large TL3 and TL4 fish targets developed for human protection.
- To ensure that wildlife species dining only on small fish are protected, staff proposes an additional target of 0.03 mg/kg methylmercury in whole TL2 and 3 fish less than 50 mm in length. This target represents the safe mercury level for prey consumed by the California least tern, a piscivorous species listed by the Federal government as endangered. Such a target for small fish also would protect the Western snowy plover and other species that consume small fish.
- Elevated fish mercury concentrations occur along the periphery of the Delta while lower body burdens are measured in the central Delta. Percent reductions in fish methylmercury levels ranging from 0% to 74% will be needed to meet the numeric targets for wildlife and human health protection in all subareas of the Delta.
- The relationships between methylmercury concentrations in largemouth bass and the trophic level food groups also were examined because largemouth bass are a good bioindicator species and only largemouth bass data are available for the same sampling period and locations as the methylmercury water data available for the linkage analysis (next chapter). It was possible to describe safe mercury ingestion rates for wildlife species and humans in terms of the mercury concentration in a standard 350-mm largemouth bass. A methylmercury concentration of 0.24 mg/kg in 350-mm length largemouth bass would fully protect humans and piscivorous wildlife species and is proposed as an implementation goal for use in the linkage analysis and determination of methylmercury allocations for point and nonpoint sources.

Options to Consider

- A variety of assumptions can be made to calculate safe fish mercury levels for humans. For example, staff recommended targets of 0.08 mg/kg and 0.24 mg/kg for large TL3 and TL4 fish, respectively, because such targets are protective of a higher consumption rate (~1 meal per week) than that used to develop the USEPA criterion (~1 meal per 2 weeks) and because available information indicates that anglers take home a mixture of TL3 and TL4 species. Application of the USEPA criterion to large TL4 fish results in a target of 0.29 mg/kg. Use of the USEPA default consumption rates of fish from TL2 (21.7%), TL3 (45.7%) and TL4 (32.6%) produces a much higher target of 0.58 mg/kg for large TL4 fish. However, as the evaluations of trophic level food group and standard 350-mm largemouth bass mercury levels indicate, a target of 0.58 mg/kg for large TL4 fish would not protect several piscivorous wildlife species, such as bald eagle, osprey, river otter, grebe, merganser, and least tern. Large TL4 fish targets of 0.29, 0.24, or 0.05 mg/kg would be protective of these species. However, a large TL4 fish target of 0.05 mg/kg may not be attainable because it is well below regional background fish mercury levels observed in the western United States.

5 LINKAGE ANALYSIS

The Delta linkage analysis focuses on the comparison of methylmercury concentrations in water and biota. The relationship has not previously been evaluated in the Delta, but statistically significant, positive correlations have been reported between aqueous methylmercury and aquatic biota elsewhere (Brumbaugh *et al.*, 2001; Foe *et al.*, 2002; Slotton *et al.*, 2003; Tetra Tech, Inc., 2005a; Sveinsdottir and Mason, 2005), indicating that methylmercury concentrations in water are one of the primary factors determining methylmercury concentrations in fish. This linkage analysis develops a Delta-specific mathematical relationship between aqueous and biotic methylmercury concentrations. The relationship is used to determine an aqueous methylmercury goal that, if met, is predicted to produce safe fish tissue levels for both human and wildlife consumption (Chapter 4). The aqueous methylmercury goal is then used to allocate methylmercury reductions for within-Delta and tributary sources (Chapter 8).

The linkage analysis has three sections. The first section describes the available fish and aqueous methylmercury data. The second section illustrates the mathematical relationship between unfiltered water and largemouth bass methylmercury levels. The mathematical relationship is used to develop an unfiltered aqueous methylmercury goal of 0.06 ng/l that corresponds to the recommended fish tissue targets that are protective of humans and wildlife that consume Delta fish. The final section provides an alternate linkage using 0.45 μ filtered methylmercury water data. Results of these correlation-based linkages are comparable to results of more empirical linkage methods, such as the evaluation of Delta areas that currently achieve the implementation goal for largemouth bass, and the use of bioaccumulation factors to calculate an aqueous methylmercury goal.

5.1 Data Used in Linkage Analysis

Fish. Water and fish have not been sampled in the Delta for the specific purpose of developing a linkage analysis. As a result, there is an acceptable overlap for only a portion of the available fish and water data. This linkage analysis focuses on recently collected largemouth bass data for several reasons. First, largemouth bass was the only species systematically collected near many of the aqueous methylmercury sampling locations used to develop the methylmercury mass balance for the Delta (next section). Second, largemouth bass are piscivorous and have some of the highest mercury levels of any fish species evaluated in the Delta. Third, bass are abundant and widely distributed throughout the Delta. Fourth, bass have high site fidelity. That is, largemouth bass maintain a localized home range; most stay within a mile of a given waterway (Davis *et al.*, 2003). Such high site fidelity makes them useful bioindicators of spatial variation in mercury accumulation in the aquatic food chain. Finally, spatial trends across the Delta in standard 350-mm largemouth bass mercury levels are representative of spatial trends in the trophic level food group mercury levels (Section 4.7). Largemouth bass were collected from 19 locations in the Delta in August/September 1998, 26 locations in September/October 1999, and 22 locations in September/October 2000 (Davis *et al.*, 2000; Davis *et al*., 2003; LWA, 2003). The year 2000 largemouth bass data were used in the linkage analysis because the exposure period of these fish had the greatest overlap with the available water data. Monthly water data were collected during the last eight months of the life of the fish. Figure 5.1 shows the water and largemouth bass methylmercury sampling locations used in the linkage analysis. The mercury concentrations in standard 350-mm largemouth bass and the corresponding water data for each sampling location are presented in Table 5.1. Section 4.8 in Chapter 4 describes the method used to calculate standard 350-mm largemouth bass mercury concentrations.

Water. Unfiltered methylmercury water samples were collected periodically between March 2000 and April 2004 at multiple Delta locations (Figure 5.1, Tables D.1 and D.3 in Appendix D). The monthly March-October 2000[28] subset of this data has the greatest overlap with the lifespan of the largemouth bass sampled in September/October 2000. The March-October 2000 and March 2000 to April 2004 data were pooled by Delta subarea to calculate monthly averages (Tables D.2 and D.3).[29] These values were used to estimate average and median methylmercury concentrations for the March-October 2000 period and annual and seasonal average and median concentrations for the March 2000 to April 2004 period (Table 5.1).[30]

Table 5.1: Fish and Water Methylmercury Values by Delta Subarea.

	Delta Subarea [a]				
	Sacramento River	Mokelumne River	Central Delta	San Joaquin River	West Delta
FISH [Sampled in September/October 2000] (mg/kg)					
Standardized 350-mm Largemouth Bass	0.72	1.04	0.19	0.68	0.31
WATER [Sampled between March and October 2000] (ng/l)					
Average	0.120	0.140	0.055	0.147	0.087
Median	0.086	0.142	0.032	0.144	0.053
WATER [Sampled between March 2000 and April 2004] (ng/l)					
Annual Average	0.108	0.166	0.060	0.160	0.083
Annual Median	0.101	0.161	0.051	0.165	0.061
Cool Season Average [b]	0.137	0.221	0.087	0.172	0.106
Cool Season Median	0.138	0.246	0.077	0.175	0.095
Warm Season Average	0.094	0.146	0.050	0.156	0.075
Warm Season Median	0.089	0.146	0.040	0.162	0.055

(a) See Figure 5.1 for the location of each water and fish collection site.
(b) For this analysis, "cool season" is defined as November through February and "warm season" is defined as March through October.

28 Coincidentally, March through October defines the season with warmer water temperatures. Aquatic biota may be more metabolically active and have a higher methylmercury bioaccumulation rate in summer. In addition, sulfate-reducing bacteria may have higher methylmercury production rates making this a critical bioaccumulation time period.

29 The methylmercury concentrations for two periods – (a) March-October 2000 and (b) September 2000 to April 2004 – were compared at each sampling location in Figure 5.1 with a paired t-test to determine whether the mean concentrations for the two time periods were different. The tests indicated no significant difference ($P \leq 0.05$) for any location. Therefore, the data for March 2000 to April 2004 (a substantially larger database than that for March-October 2000) were also evaluated in the linkage analysis.

30 Monthly averages were used to ensure that the seasonal and annual values were not biased by months with different sample sizes.

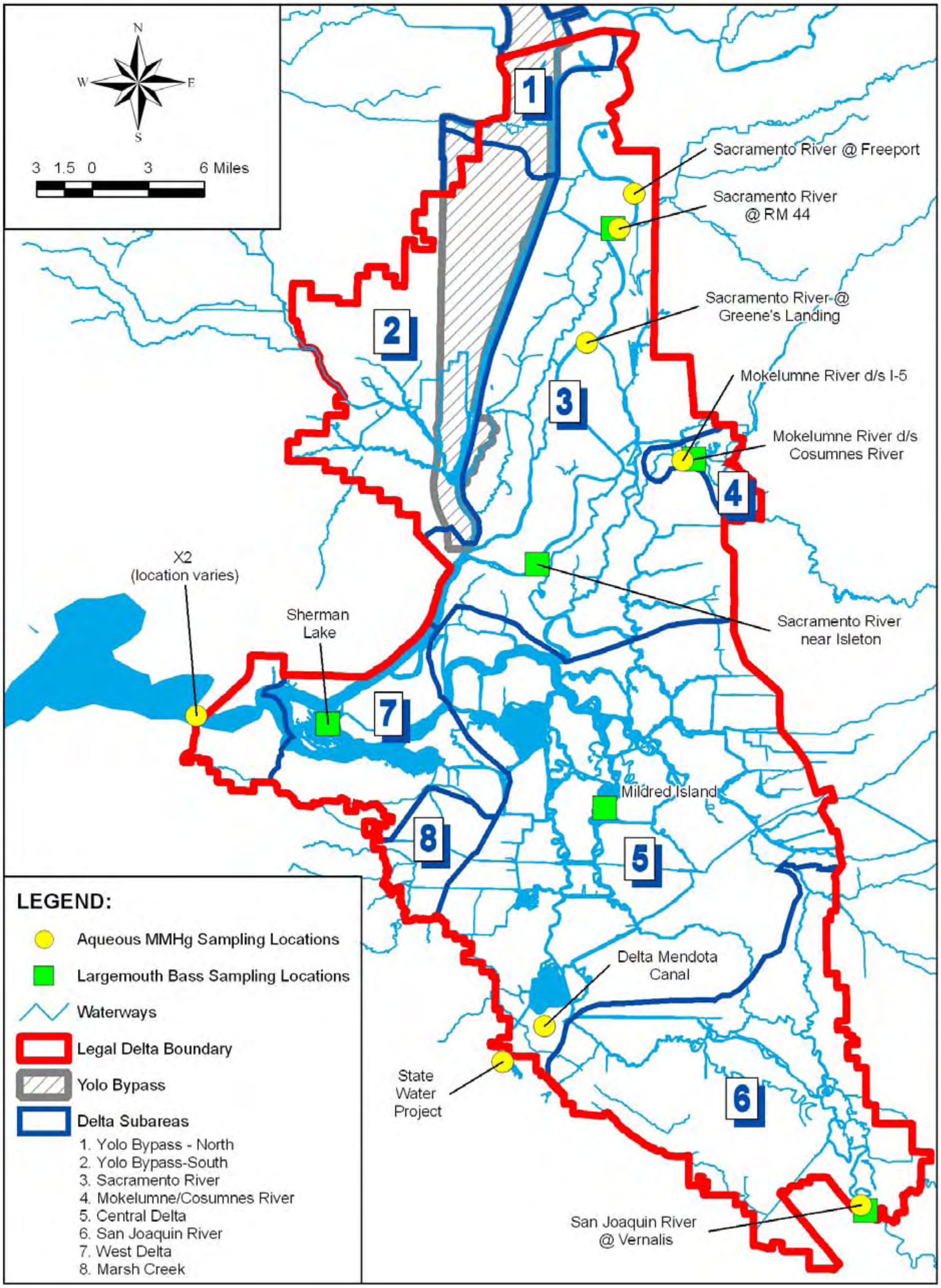

Figure 5.1: Aqueous and Largemouth Bass Methylmercury Sampling Locations Used in the Linkage Analysis.

5.2 Bass/Water Methylmercury Regressions & Calculation of Aqueous Methylmercury Goal

The mercury concentrations in standard 350-mm largemouth bass for each Delta subarea were regressed against the average and median unfiltered aqueous methylmercury levels for the March to October 2000 and March 2000 to April 2004 periods to determine whether relationships might exist (Figure 5.2, Table 5.2, and Figure D.1 in Appendix D). The regressions were evaluated using linear, exponential, logarithmic, and power curves. Power curves provided the best fit, although all the regression types demonstrated a positive relationship between aqueous and biotic methylmercury concentrations. In each scenario described by Table 5.2, increasing the aqueous methylmercury concentration results in increasing fish tissue levels. All the scenarios were statistically significant ($P < 0.05$).

The recommended implementation goal for fish methylmercury in the Delta is 0.24 mg/kg (wet weight) in a standard 350-mm largemouth bass (Chapter 4). Substitution of 0.24 mg/kg into the equations in Table 5.2 results in predicted average and median safe water methylmercury values that range from 0.04 to 0.09 ng/l. The lowest concentration is predicted by the regression based on median March to October 2000 water values (Scenario 1B) while the highest concentration is predicted by the regression based on average cool season water concentrations (Scenario 3A).

Staff recommends that **0.06 ng/l methylmercury in unfiltered water** be used as an **implementation goal** for the determination of load allocations (Chapter 8). This recommendation is based on Scenario 1A in Table 5.2 and incorporates an explicit margin of safety of about 10%. The goal could be applied as an annual average methylmercury concentration. Staff recommends this value because only the March to October 2000 period overlapped the lifespan of the largemouth bass analyzed for mercury body burden. Also, little is known about the seasonal exposure regime controlling methylmercury concentrations in aquatic biota. Therefore, an annual average was selected as it weights all seasons equally.

The recommended implementation goals for largemouth bass and ambient water methylmercury in the Delta are based on Scenario B.4 from Table 4.5 in Chapter 4. Scenarios A.1, A.4, B.4 and E.3 are evaluated as fish tissue objective alternatives in the draft Basin Plan Amendment staff report. Table 5.3 shows the ambient water methylmercury levels that correspond to all the objective alternatives.

Progress towards attaining Alternative 5 in Table 5.3 would be difficult to track. This is because Alternative 5 (0.05 mg/kg in large TL4 fish) is substantially below existing conditions anywhere in the Delta, thus making it difficult to accurately extrapolate from methylmercury in fish to corresponding methylmercury in water. Such extrapolation for Alternative 5 produces a concentration of 0.028 ng/l methylmercury in water, which is below the current minimum reporting level for laboratory analyses for methylmercury. (Minimum reporting levels are equivalent to the lowest calibration standard for methylmercury, which is currently 0.05 ng/l.) Though water methylmercury concentrations below the minimum reporting level can be detected, they cannot be quantified accurately; thus, Alternative 5 progress would be difficult to quantify and track. The other fish tissue objective alternatives correspond to water methylmercury concentrations above the minimum reporting level of 0.05 ng/l and thus can be quantified accurately.

The linkage analysis for the Delta relies upon sequential correlations to determine the numerical aqueous methylmercury goal. A potential problem with the analysis is that each correlation has an associated error term. No attempt has been made to estimate these errors and propagate them from one correlation to the next when calculating the recommended aqueous methylmercury goal. There are two alternate, more empirical, approaches. The first approach is to compare existing largemouth bass and aqueous methylmercury levels to the proposed implementation goals. The average March-October 2000 methylmercury concentration in the Central Delta (0.055 ng/l, Table 5.1) is less than the proposed aqueous goal of 0.06 ng/l while concentrations in the West Delta (0.087 ng/l) are higher. Similarly, the methylmercury concentration in standard 350-mm bass in the Central Delta is 0.19 mg/kg while the concentration in the West Delta is 0.31 mg/kg (Table 4.10). The recommended implementation goal is 0.24 mg/kg in standard 350-mm largemouth bass. Therefore, empirical observations suggest that the "correct" aqueous methylmercury goal to achieve safe mercury levels in the various trophic level food groups must lie between 0.055 and 0.087 ng/l. If the aqueous methylmercury goal of 0.06 ng/l is attained in the Delta, then methylmercury concentrations in all trophic level food groups are predicted to fall within the safe tissue concentration range.

A second linkage approach that does not rely on the correlation between largemouth bass and water methylmercury concentrations to derive an implementation goal for water makes use of bioaccumulation factors (BAFs), an approach used in numerous USEPA-approved TMDLs across the country.[31] A BAF is the ratio of the concentration of a chemical in fish tissue to the concentration of the chemical in the water column. By definition, BAFs imply a linear relationship between methylmercury in the water column and in fish. Section D.2 in Appendix D describes the method used to develop BAF-based implementation goals for the Delta and its subareas using standard 350-mm largemouth bass and average aqueous methylmercury concentrations. The resulting safe aqueous methylmercury levels ranged from 0.029 to 0.069 ng/l, slightly less than but comparable to the safe levels produced using the regression-based approach. The similarity most likely occurs because both methods used the same fish and water data, and because the regression described in Figure 5.2(A) is nearly linear at low fish and water methylmercury levels. However, the regression-based method is preferred because it does not inherently assume a linear relationship between fish and water methylmercury levels.

The safe aqueous methylmercury concentrations predicted for the Delta are comparable to analysis results for Cache Creek and nationwide studies. Brumbaugh and others (2001) found in a national survey of 106 stations from 21 basins that one-time unfiltered methylmercury water samples collected during the fall season were also positively correlated with largemouth bass tissue levels. An aqueous methylmercury concentration of 0.058 ng/l was predicted to produce three-year old largemouth bass[32] with 0.3 mg/kg mercury tissue concentration. In the Cache Creek watershed, an unfiltered methylmercury concentration of 0.14 ng/l corresponded with the production of 0.23 mg/kg mercury in large fish (Cooke *et al.*, 2004). Predicted safe

[31] Refer to: http://www.epa.gov/OWOW/tmdl/index.html.

[32] 262-mm average length fish.

methylmercury water values for the Delta are bracketed by safe water concentrations determined by the national and Cache Creek studies.

Additional fish and methylmercury water studies that address uncertainties in the linkage analysis are planned. These include additional evaluations of standard 350-mm largemouth bass tissue concentrations at more locations in the Delta after multiple years of aqueous methylmercury data have been obtained. Studies also are planned to better determine the seasonal exposure regime when most of the methylmercury is sequestered in the aquatic food chain. The results of these studies may lead to future revisions in the proposed aqueous methylmercury goal.

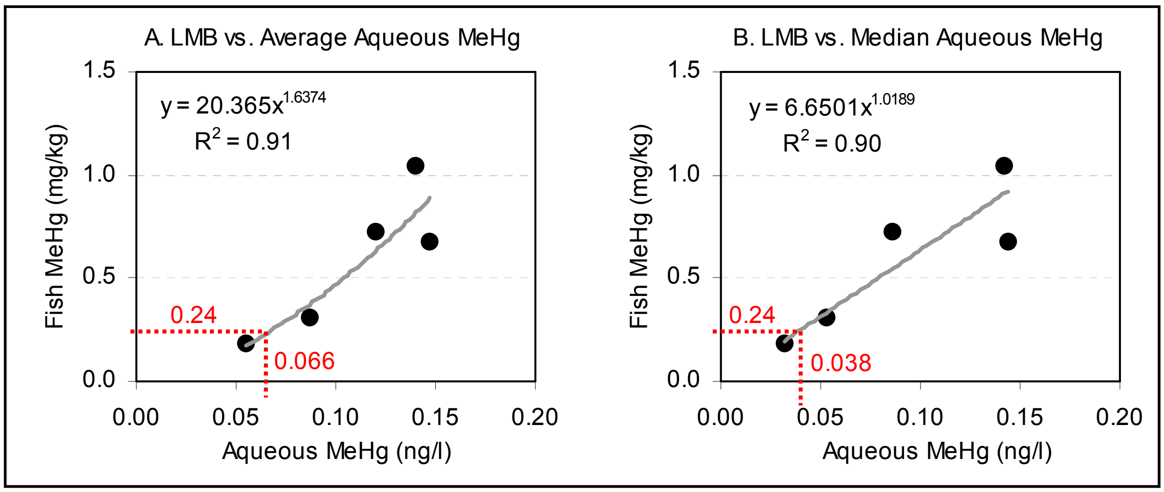

Figure 5.2: Relationships between Standard 350-mm Largemouth Bass Methylmercury and March to October 2000 Unfiltered Aqueous Methylmercury.
The proposed implementation goal for standard 350-mm largemouth bass is 0.24 mg/kg.

Table 5.2: Relationships between Methylmercury Concentrations in Water and Standard 350-mm Largemouth Bass

Aqueous MeHg Data Period	Scenario	Regression Equation	$R^{2\,(a)}$	Aqueous MeHg Conc. (ng/l) Corresponding to LMB value of 0.24 mg/kg
1. March to October 2000	A. Average Aqueous MeHg	$y = 20.365x^{1.6374}$	0.91	0.066
	B. Median Aqueous MeHg	$y = 6.6501x^{1.0189}$	0.90	0.038
2. March 2000 to April 2004 - Annual -	A. Average Aqueous MeHg	$y = 14.381x^{1.51}$	0.88	0.066
	B. Median Aqueous MeHg	$y = 8.0903x^{1.1926}$	0.86	0.052
3. March 2000 to April 2004 - Cool Season -	A. Average Aqueous MeHg	$y = 17.795x^{1.8007}$	0.90	0.092
	B. Median Aqueous MeHg	$y = 8.8725x^{1.4347}$	0.92	0.081
4. March 2000 to April 2004 - Warm Season -	A. Average Aqueous MeHg	$y = 11.528x^{1.339}$	0.83	0.055
	B. Median Aqueous MeHg	$y = 6.8941x^{1.0723}$	0.85	0.044

(a) All R^2 values are statistically significant at $P<0.05$. Regression graphs are provided in Figure 5.2 and Appendix D.

Table 5.3. Ambient Water Methylmercury Concentrations that Correspond to Alternative Fish Tissue Objectives Evaluated in the Basin Plan Amendment Staff Report.

Fish Tissue Objective Alternative [(a)]	**Scenario # from Table 4.5**	**150-500 mm TL3 Fish Tissue Target** (mg/kg)	**150-500 mm TL4 Fish Tissue Target** (mg/kg)	**Predicted Standard 350-mm Largemouth Bass (LMB) MeHg Concentration for TL3 Fish Target** (mg/kg) [(b)]	**Predicted Standard 350-mm LMB MeHg Concentration for TL3 Fish Target** (mg/kg) [(b)]	**Ambient Water MeHg Concentration that Corresponds to the Lowest Predicted LMB Concentration for the Alternative** (ng/l) [(b)]
2	A.1	0.20	0.58	0.79	0.68	0.125
3	A.5	- - -	0.29		0.34	0.082
4	B.4	0.08	0.24	0.24	0.28	0.066
5	E.3	- - -	0.05		0.06	0.028

(a) Alternative numbers from Table 3.1 in the Basin Plan Amendment Staff Report. "Alternative 1" is the "no action" alternative and has a narrative objective rather than a numeric objective.

(b) Predicted standard 350-mm largemouth bass methylmercury concentrations that correspond to the TL3 fish targets were calculated using the equation provided in Figure 4.5 for "Human Target [150-500 TL3 Fish]". Predicted standard 350-mm largemouth bass methylmercury concentrations that correspond to the TL4 fish targets are based on the equation provided in Figure 4.5 for "Human Target [150-500 TL4 Fish]".

(c) Ambient water methylmercury concentrations that corresponds to the predicted largemouth bass concentrations were calculated using the equation for Scenario 1A in Table 5.2.

5.3 Evaluation of a Filtered Aqueous Methylmercury Linkage Analysis

This section presents an alternate linkage analysis based on filter-passing[33] aqueous methylmercury data. Methylmercury concentrations in standard 350-mm largemouth bass for each Delta subarea (Table 5.1) were regressed against the average and median filtered aqueous methylmercury levels for March-October 2000 (Table 5.4 and Table D.4 in Appendix D). Figure 5.3 demonstrates that there is a statistically significant positive correlation between filter-passing aqueous and largemouth bass tissue methylmercury levels. However, average and median filter-passing methylmercury water values for the Central Delta and Western Delta, regions that define the lower end of the regression, are determined mainly by values lower than the method detection limit (0.022 ng/l). Furthermore, substitution of the recommended implementation goal of 0.24 mg/kg mercury for 350 mm largemouth bass in the equations in Figure 5.3 results in predicted average and median safe water values (0.016 ng/l and 0.010 ng/l, respectively) below the method detection limit. Similarly low levels resulted when the BAF-based linkage method was used (see Section D.2 in Appendix D). Staff does not recommend adoption of a methylmercury goal that is unquantifiable with present analytical methods.

Key points to consider for the linkage analysis are listed after Table 5.4 and Figure 5.3.

[33] Water samples were filtered using 0.45-micrometer capsule filters. Much of the methylmercury measured in filtered samples is colloidal (Choe, 2002). Hence the results are called "filter-passing" rather than "dissolved".

Table 5.4: Average and Median Filtered Methylmercury Concentrations (ng/l) for March 2000 to October 2000 for Each Delta Subarea.

	Delta Subarea [(a)]				
	Sacramento River	Mokelumne River	Central Delta	San Joaquin River	West Delta
Average	0.043	0.078	0.029	0.037	0.019
Median	0.039	0.069	0.014	0.036	0.011

(a) See Figure 5.1 for the location of each water and fish collection site. See Appendix L for raw data and Table D.4 in Appendix D for monthly averages, upon which these average and median values are based.

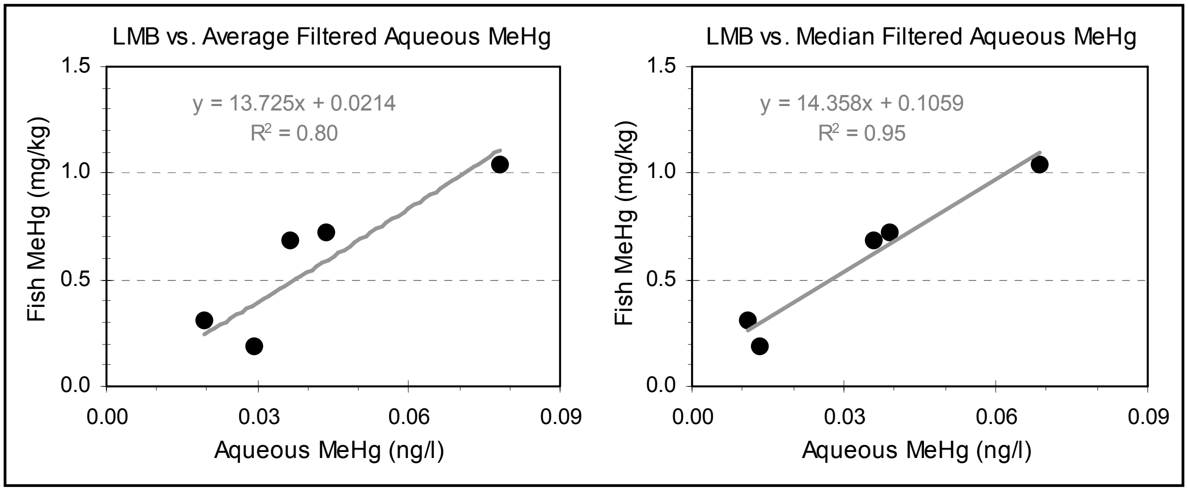

Figure 5.3: Relationships between Standard 350-mm Largemouth Bass Mercury Levels and March to October 2000 Filtered Aqueous Methylmercury. The proposed implementation goal for standard 350-mm largemouth bass is 0.24 mg/kg.

Key Points

- Statistically significant mathematical relationships exist between unfiltered and filter-passing methylmercury concentrations in water and fish tissue.
- Based on the relationship between average March to October 2000 unfiltered methylmercury concentrations in water and methylmercury in standard 350-mm largemouth bass tissue, staff recommends an implementation goal for ambient Delta waters of 0.06 ng/l unfiltered methylmercury. The proposed goal incorporates an explicit margin of safety of about 10%. Staff recommends that the goal be applied as an annual average methylmercury concentration.
- More empirical linkage methods, such as the evaluation of Delta areas that currently achieve the implementation goal for largemouth bass and the use of bioaccumulation factors to calculate an aqueous methylmercury goal, predict safe aqueous methylmercury levels comparable to the correlation-based linkage method.

6 SOURCE ASSESSMENT – METHYLMERCURY

The Delta mercury TMDL program addresses the sources of two constituents, methyl and total mercury. The program focuses on methylmercury because, as described in Chapter 5, the Delta linkage analysis demonstrated a statistically significant, positive correlation between methylmercury levels in ambient water and fish tissue. The program also addresses total mercury for several reasons: methylmercury production has been found to be a function of the total mercury content of sediment (Chapter 3); the mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion for total recoverable mercury in freshwater sources; and the mercury control program for San Francisco Bay has assigned a total mercury load reduction of 110 kg/yr to the Central Valley (Johnson and Looker, 2004). Sources and losses of methylmercury are described in this chapter. Sources and losses of total mercury and suspended sediment are described in Chapter 7. All of the mass load calculations are based on Equation 6.1:

Equation 6.1:

$$M_x = C_x * V$$

Where: M_x = Mass of constituent, X

C_x = Concentration of constituent, X, in mass per volume

V = Volume of water

Average annual methylmercury loads were estimated for water years (WY) 2000 to 2003, a relatively dry period that encompasses the available methyl and total mercury concentration data for the major Delta inputs and exports. Section 6.1 and Appendix E describe the water volumes upon which the loads are based. Sections 6.2 and 6.3 describe the methylmercury concentration data for all major sources and sinks and identify data gaps and uncertainties. Section 6.4 reviews the results and potential implications of the methylmercury mass balance. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the measurements and of the importance of other unknown processes at work in the Delta.

6.1 Water Budget

Water inputs and losses were evaluated for the WY2000-2003 period, a relatively dry period that encompasses the available methylmercury concentration data for the major Delta inputs and exports (Section 6.2). In addition, the WY1984-2003 period was evaluated to illustrate the importance of wet years, particularly for total mercury and sediment loading from the Yolo Bypass (Chapter 7). This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. An assessment of a typical distribution of wet and dry water years is critical to the understanding of mercury and sediment sources because, given the interannual variability in Sacramento Basin flows and mercury loads, and high daily loads associated with large storm events, the load transported by several high flow days may be equivalent to the annual load from the Sacramento River Basin during a dry year (see Figure E.1 and Table I.2 in Appendices E and I, respectively).

Water volume information for Delta inputs and exports was obtained from a variety of sources. USGS and DWR gages provided daily flows for the major tributaries to the Delta. The Dayflow model was used to estimate daily flow to San Francisco Bay, the Delta Mendota Canal (DMC), and the State Water Project (SWP). The Delta Island Consumptive Use Model was used to estimate Delta agricultural diversion and return flows. Average annual precipitation and land use acreages were used to estimate wet weather inputs from urban areas, atmospheric deposition, and tributaries without flow gages. Project files were reviewed to determine average annual discharges from NPDES-permitted facilities in the Delta and annual average volumes removed by dredging projects. Appendix E provides a detailed description of the methods used to estimate annual average flow for the different water sources.

The WY2000-2003 water budget balances within about 5%, and the WY1984-2003 water budget balances to within about 1% (Table 6.1). This indicates that all major water inputs and exports have been identified. The Sacramento River, San Joaquin River and Yolo Bypass are the primary water sources, with the Sacramento River providing the majority of flow. The primary sinks are San Francisco Bay and the State and Federal pumps that transport water to the southern part of the State. The majority of water movement in the Delta is down the Sacramento River to San Francisco Bay and through a series of interconnecting channels to the State and Federal pumps. Most of the water in winter and spring flows to San Francisco Bay, while in summer and fall the State and Federal pumps export a larger fraction south of the Delta (DWR, 1995).

6.2 Methylmercury Sources

The following were identified as sources of methylmercury to the Delta/Yolo Bypass: tributary inflows from upstream watersheds, sediment flux, municipal wastewater, agricultural drainage, and urban runoff. Table 6.2 lists the average methylmercury concentrations and estimated average annual loads for each for WY2000-2003. The following sections illustrate the locations of the sources, describe the available methylmercury concentration data, and identify data gaps and uncertainties associated with the load estimates. Figures and tables cited in the text are arranged at the end of each source-specific section in the order in which they were mentioned.

Table 6.1: Average Annual Water Volumes for Delta/Yolo Bypass Inputs and Losses

Inputs & Exports	WY2000-2003		WY1984-2003	
	Water Volume (M acre-feet/yr)	% All Water	Water Volume (M acre-feet/yr)	% All Water
Tributary Sources (% of All Inputs)				
Sacramento River	15.1	75%	16.1	68%
San Joaquin River	1.8	9.0%	3.0	13%
Fremont Weir Spills to Yolo Bypass	1.1	5.5%	1.9	8.0%
Mokelumne-Cosumnes River	0.43	2.4%	0.69	2.9%
Knights Landing Ridge Cut	0.27	1.3%	0.33	1.4%
Cache Creek Settling Basin	0.22	1.1%	0.38	1.6%
Calaveras River	0.15	0.75%	0.16	0.68%
French Camp Slough	0.064	0.32%	0.067	0.28%
Willow Slough & Bypass	0.062	0.31%	0.068	0.29%
Morrison Creek	0.061	0.30%	0.064	0.27%
Putah Creek	0.041	0.20%	0.11	0.47%
Ulatis Creek	0.032	0.16%	0.033	0.14%
Bear/Mosher Creeks	0.029	0.14%	0.030	0.13%
Dixon Area	0.012	0.06%	0.012	0.05%
Marsh Creek [(a)]	0.006	0.03%	0.006	0.03%
Other Small Drainages to Delta [(b)]	0.082	0.41%	0.082	0.35%
Sum of Tributary Inputs	**19.51**	**97.1%**	**23.03**	**97.5%**
Within-Delta Sources (% of All Inputs)				
Wastewater (Municipal & Industrial)	0.27	1.4%	0.27	1.1%
Atmospheric (Direct)	0.089	0.45%	0.092	0.39%
Atmospheric (Indirect)	0.16	0.80%	0.17	0.72%
Urban	0.059	0.30%	0.061	0.26%
Sum of Within-Delta Inputs	**0.58**	**2.9%**	**0.59**	**2.5%**
Exports (% of All Exports)				
Outflows to San Francisco Bay [X2]	12	63%	17	73%
State Water Project	3.2	17%	2.6	11%
Delta Mendota Canal	2.5	13%	2.4	10%
Agricultural Diversions [(a)]	0.99	5%	0.99	4.2%
Evaporation	0.30	2%	0.3	1.3%
Dredging [(a)]	0.00024	0.001%	0.00024	0.001%
Sum of Inputs	**20.09 M acre-feet**		**23.63 M acre-feet**	
Sum of Exports	**18.99 M acre-feet**		**23.29 M acre-feet**	
Input - Export	**1.10 M acre-feet**		**0.33 M acre-feet**	
Exports / Inputs	**95%**		**99%**	

(a) Only WY2001-2003 flow data were available for Marsh Creek. Agricultural diversion volume is based on WY1999. The water volume removed by dredging is a 10-year average. The same water volumes for these inputs and exports, and for the Wastewater input, were used in both water budget periods.

(b) "Other Small Drainages to Delta" include the following areas shown on Figure 6.1, for which methylmercury, total mercury and TSS concentration data are not available: Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

Table 6.2: Methylmercury Concentrations and Loads to the Delta/Yolo Bypass for WY2000-2003.

	Average Annual Load (g/yr)	**% All MeHg**	**Average Aqueous Concentration** (ng/l)
Tributary Sources			
Sacramento River @ Freeport	2,026	39%	0.10
San Joaquin River near Vernalis	356	6.8%	0.16
Fremont Weir Spills to Yolo Bypass	177	3.4%	0.10
Cache Creek Settling Basin	137	2.6%	0.50
Mokelumne River near I-5	108	2.1%	0.17
Knights Landing Ridge Cut	100	1.9%	0.19
Calaveras River [b]	26	0.50%	0.14
Willow Slough & Bypass [a]	18	0.34%	0.24
Putah Creek	11	0.21%	0.18
Bear/Mosher Creeks [b]	11	0.21%	0.31
French Camp Slough [b]	11	0.21%	0.14
Ulatis Creek [b]	9.5	0.18%	0.24
Morrison Creek [b]	7.5	0.14%	0.10
Dixon Area [a]	3.6	0.07%	0.24
Marsh Creek @ Highway 4 [c]	1.9	0.04%	0.25
Other Small Drainages to Delta	*unknown*		
Sum of Tributary Sources	**3,004**	**58%**	**- - -**
Within-Delta Sources			
Wetland Habitats	983	19%	- - -
Open Water Habitats	861	17%	- - -
Wastewater	204	3.9%	<0.02 to 1.7
Agricultural Lands	123	2.4%	- - -
Atmospheric Deposition	23	0.44%	- - -
Urban	20	0.38%	0.24
Sum of Within-Delta/Yolo Bypass Sources	**2,215**	**42%**	**- - -**
TOTAL MeHg INPUTS:	**5,219 g/yr (5.2 kg/yr)**		

(a) Methylmercury data were not available for Willow Slough, Willow Slough Bypass, and Dixon Area runoff. The average methylmercury concentration for Ulatis Creek was used to estimate their inputs to the Yolo Bypass because they have similar land uses as the Ulatis Creek watershed.

(b) Average wet weather methylmercury concentrations are shown for the small watersheds rather than average annual concentrations.

(c) Only WY2001-2003 flow data were available for Marsh Creek.

6.2.1 Tributary Inputs

Tributaries contribute almost 60% of Delta methylmercury inputs (Table 6.2). Figure 6.1 illustrates the tributary watersheds that drain directly or indirectly to the Delta within its legal boundary. The following watershed areas drain directly to the Delta:

- Calaveras, Mokelumne, Sacramento, and San Joaquin Rivers;
- Bear, Marsh, Mosher, Morrison, and Ulatis Creeks;
- Prospect and Shag Sloughs, which drain the Yolo Bypass;
- French Camp Slough and Upper Lindsay/Cache Slough area; and
- Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

The primary drainage in the Yolo Bypass is the Toe Drain, which drains southward to Prospect Slough in the legal Delta. However, depending on the level of inundation in the Yolo Bypass, about 20% of the incoming water may drain to the Delta by way of Shag Slough (Foe *et al.*, 2007). The following watershed areas drain to the Yolo Bypass upstream of Prospect and Shag Sloughs:

- Cache Creek Settling Basin
- Fremont and Sacramento Weirs
- Knights Landing Ridge Cut
- Putah Creek
- Willow Slough and Willow Slough Bypass
- Dixon Area

Putah Creek drains to the Yolo Bypass downstream of the legal Delta boundary, while the rest of the watershed areas drain to it upstream of the legal Delta boundary. Fremont and Sacramento Weirs convey floodwaters from the Sacramento and Feather Rivers, Sutter Bypass and their associated tributary watersheds. The Knights Landing Ridge Cut is an overflow channel that connects the Colusa Basin Drain to the Yolo Bypass (see Figure 6.1 and Figure E.2 in Appendix E).

Several sampling efforts have taken place to characterize tributary inputs to the Delta and Yolo Bypass. Figure 6.2 shows the tributary methylmercury monitoring locations. Appendix L provides the methylmercury concentration data collected at each tributary location and Table 6.3 and Figure 6.3 summarize the data.

Central Valley Water Board staff conducted monthly aqueous methylmercury sampling in the four major tributaries – Sacramento River, San Joaquin River, Mokelumne River, and Prospect Slough – from March 2000 to September 2001 (Foe, 2003). In addition, other programs conducted periodic aqueous methylmercury sampling on the Sacramento River between July 2000 and June 2003 (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Monthly sampling of the major tributaries and periodic sampling of other tributaries by Central Valley Water Board staff resumed in April 2003. Of the three Sacramento River sampling locations included in the linkage analysis (Chapter 5) – Freeport, River Mile 44 and Greene's Landing – Freeport is the most upstream location and is used to characterize loads from the Sacramento River watershed[34] (Table 6.2).

The Sacramento Weir did not spill to the Yolo Bypass during WY2000-2003; hence, no methylmercury load estimate was made for Sacramento Weir inputs. Methylmercury loads contributed by Fremont Weir spills were estimated using methylmercury concentration data collected from the Sacramento River at Colusa because field observations indicate that Fremont Weir spills are typically comprised of flows from the Sacramento River upstream of the Feather River confluence (Foe, pers. comm.). Methylmercury loads contributed by the Knights Landing Ridge Cut were estimated using methylmercury concentration data collected from the Colusa Basin Drain at Knights Landing.

Methylmercury data were not available for several of the small watersheds and drainage areas that discharge to the Delta and Yolo Bypass. The average methylmercury concentration for Ulatis Creek was used to estimate Willow Slough/Bypass, Upper Lindsay/Cache Slough, and Dixon area inputs because they have similar land uses as the Ulatis Creek watershed and are adjacent to each other. No methylmercury load estimates were made for the other small drainage areas (Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas); given that these areas contribute only about one third of a percent of all water inputs to the Delta/Yolo Bypass, methylmercury loads from these areas are not expected to be substantial.

Regressions between methylmercury concentration and daily flow were evaluated for each tributary input with available flow gage records to determine whether concentrations could be predicted from flow (Appendix F). Only the regression for the Sacramento River was significant ($P<0.05$). The Sacramento River regression explained 12% of the variation in methylmercury concentrations. Lack of a relationship between methylmercury concentrations and flow at all sites except the Sacramento River suggests that flow is unlikely to be a useful surrogate for methylmercury concentrations. The relationship at Freeport may be a statistical anomaly. Therefore, average methylmercury concentrations were used to estimate all tributary loads. For tributary inputs with a monthly sampling frequency (Table 6.3), concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Table F.1 in Appendix F). The monthly average concentrations were multiplied by monthly average flow volumes (Table F.2) to estimate loads; monthly loads were summed to calculate an annual average methylmercury load for WY2000-2003. For all the tributaries with less frequent sampling, loads were estimated by multiplying average annual water volume for WY2000-2003 (Table 6.1) by the average wet weather methylmercury concentration for each tributary input (Table 6.3).

Methylmercury loads in Yolo Bypass outflows at Prospect Slough were evaluated for comparison to Yolo Bypass inputs and other major tributaries (e.g., the Sacramento and San Joaquin Rivers). Methylmercury concentration data for Shag Slough outflows were not available. Although sampling took place on a regular basis at Prospect Slough in the Yolo

[34] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 6.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 6.2 incorporates a small portion of the within-Delta urban runoff loading.

Bypass, only six sampling events occurred when there was net advective outflow at the Lisbon Weir (Appendix E, Section E.2.2). Dispersive or tidal flows also transport loads from the Bypass below the Lisbon Weir during almost all times; however, the actual amount is unknown at present. Therefore, annual methylmercury loading from Prospect Slough was estimated by multiplying average methylmercury concentrations observed when the slough had net outflow (0.346 ng/l) by the annual average net advective outflow from the Yolo Bypass (1.0 M acre-ft/yr for WY2000-2003, see Appendix E, Section E.2.2).

The resulting Yolo Bypass load (443 g/yr) is comparable to the sum of watershed inputs to the Yolo Bypass (440 g/yr). However, this load estimate probably underestimates export from the Bypass because, although it is based on the estimated total outflow from the Bypass, it uses methylmercury concentrations observed at Prospect Slough, and does not include outflows from Shag Slough. Recent data indicate that Shag Slough has elevated methylmercury concentrations (Foe *et al.*, 2007), possibly due to its proximity to mercury-contaminated inputs from Cache and Putah Creeks. Even so, this uncertainty is unlikely to substantially affect the load estimates for WY2000-2003, a relatively dry period (Appendix E, Section E.1). For example, the Fremont Weir and Cache Creek Settling Basin weir, the primary tributary water sources to the Yolo Bypass, did not spill at all during WY2001 (see Appendix E, Figure E.4). Foe and others (2007) found the Yolo Bypass to be a net producer of methylmercury, when conveying floodwaters. More study needs to take place to determine how much methylmercury is produced within the Yolo Bypass and how much is delivered from upstream watersheds during both wet and dry years. Central Valley Water Board staff is currently conducting such a study; final results are expected in 2008.

The Sacramento River was the primary tributary source of methylmercury (2.0 kg/yr) during WY2000-2003 (Table 6.2). LWA (2002) calculated an annual average methylmercury load of 3.2 ±1.6 kg/yr for the Sacramento River at Freeport for 1980-1999 (a wetter period than the TMDL base period). Foe (2003) also concluded that the Sacramento River was the major methylmercury tributary source in all months between March 2000 and September 2001, except for March 2000 when the Yolo Bypass was flooded and it became the primary source of methylmercury. Water years 2000 through 2003 were considered normal to dry years in the Sacramento and San Joaquin watersheds. Therefore, tributary loads for the TMDL study period may underestimate long-term values. In particular, the Yolo Bypass may provide a more substantial methylmercury load to the Delta when flooded for prolonged periods, as in 1997 and 1998.

The Central Valley Water Board has conducted additional methylmercury monitoring on all major tributary inputs to the Delta and Yolo Bypass. The study will be completed and a report published in 2008.

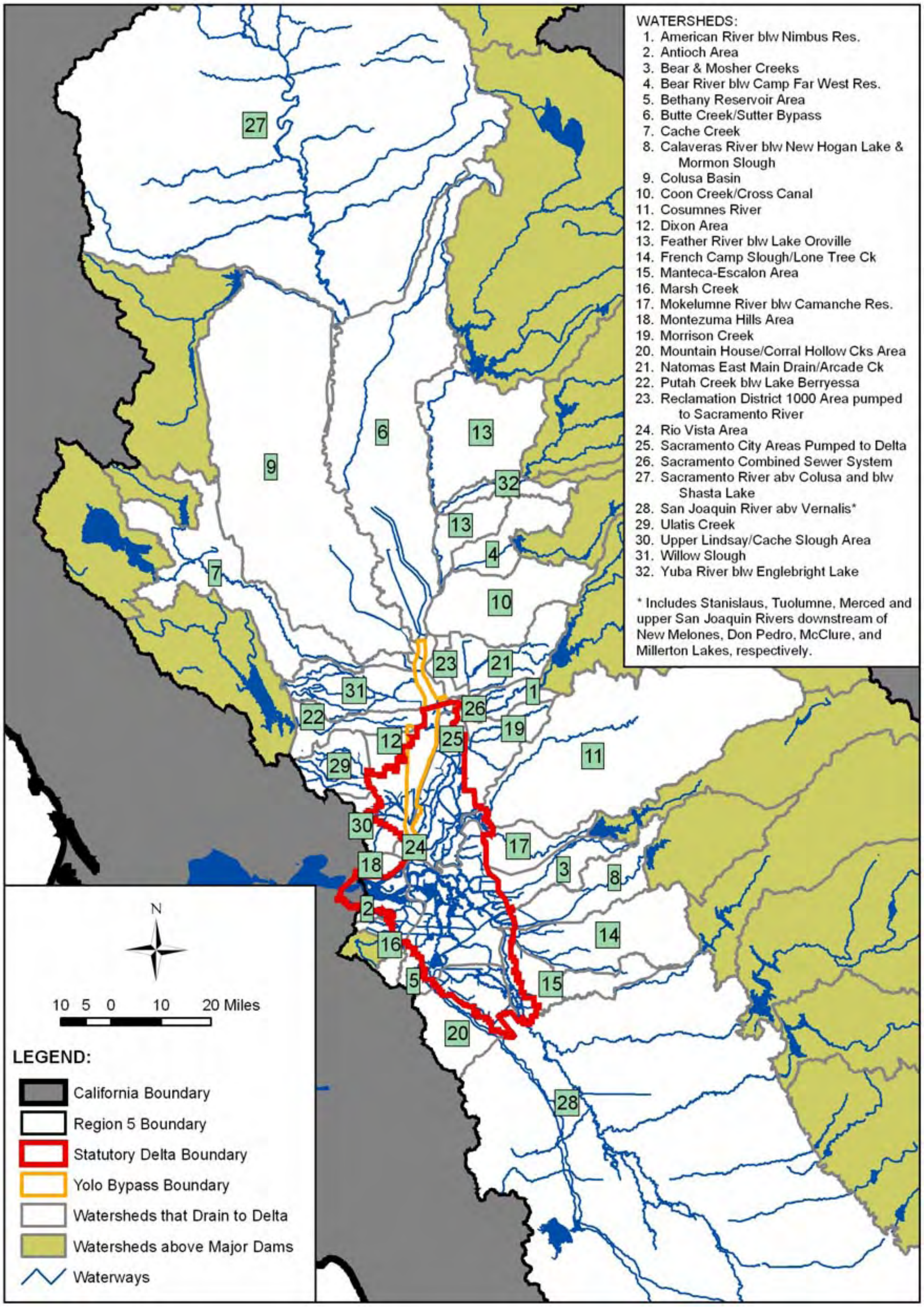

Figure 6.1: Watersheds that Drain to the Delta and Yolo Bypass.

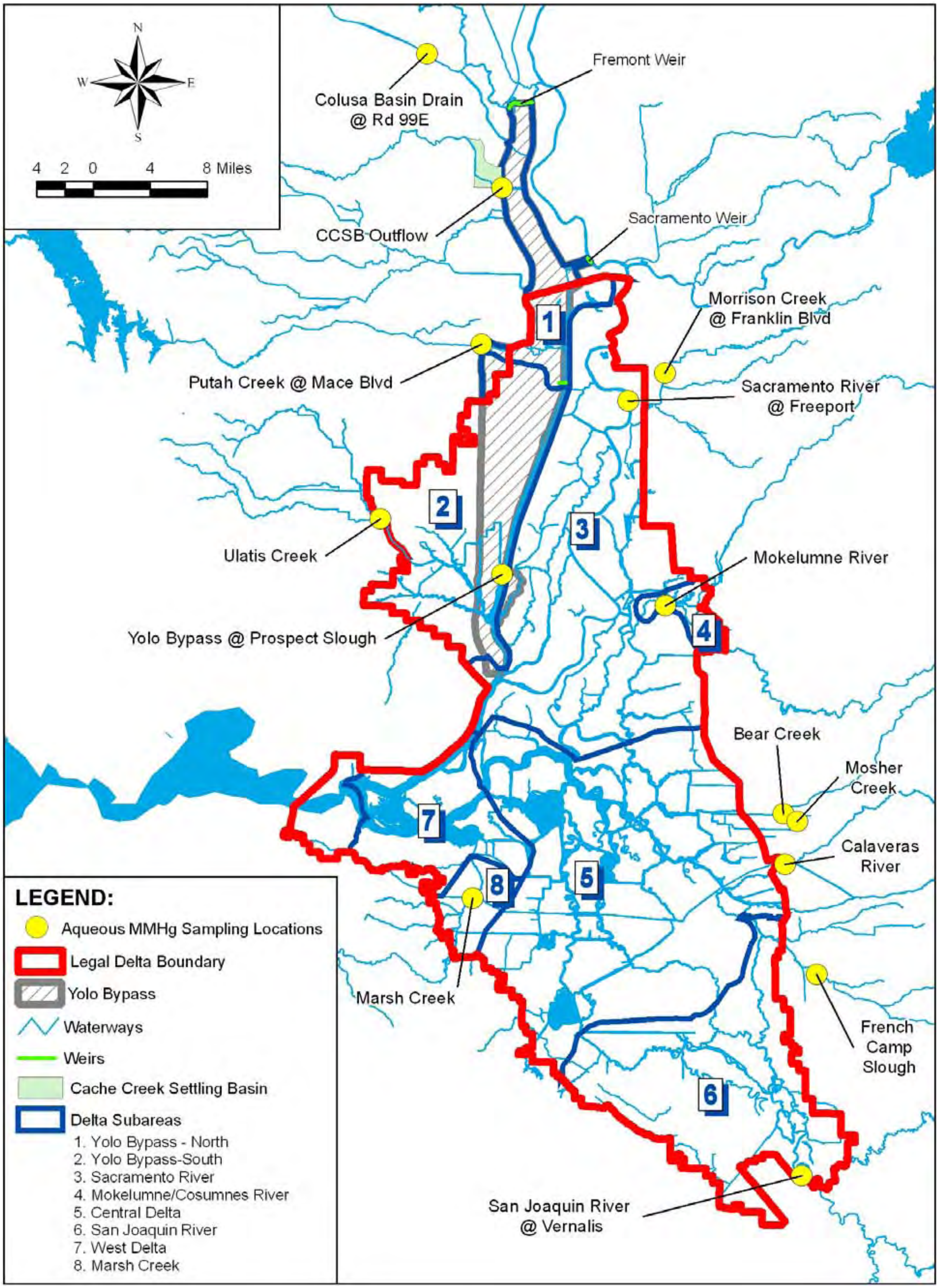

Figure 6.2: Tributary Aqueous Methylmercury Monitoring Locations

Table 6.3: Methylmercury Concentrations for Tributary Inputs.

Site [(a)]	# of Samples	Sampling Begin Date	Sampling End Date	Min. MeHg Conc. (ng/l)	Ave. MeHg Conc. (ng/l)	Annual Ave. MeHg (ng/l) [(a)]	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Large Tributaries to the Delta								
Cache Creek Settling Basin Outflow	8	3/1/2000	9/29/2003	0.155	0.504	0.504	0.432	0.991
Fremont Weir (Sacramento River @ Colusa)	30	7/20/2000	9/15/2003	0.041	0.105	0.097 (0.102) [(b)]	0.089	0.327
Knights Landing Ridge Cut (Colusa Basin Drain @ Road 99E)	21	7/21/2000	9/15/2003	0.080	0.214	0.191	0.125	0.552
Mokelumne River @ I-5	23	3/28/00	9/30/03	0.011	0.153	0.166	0.167	0.320
Putah Creek @ Mace Blvd	23	3/28/2000	9/29/2003	0.053	0.197	0.180	0.126	1.120
Prospect Slough (Yolo Bypass) [(c)]	22 (6)	3/28/00	9/30/03	0.114 (0.142)	0.256 (0.346)	0.273 (0.346)	0.209 (0.312)	0.701 (0.701)
Sacramento River @ Freeport	36	7/18/00	6/11/03	0.050	0.105	0.103	0.097	0.242
San Joaquin River @ Vernalis	31	3/28/00	4/12/04	0.093	0.156	0.160	0.147	0.256
Small Tributaries to the Delta								
Bear Creek @ West Lane	3	2/2/04	2/26/04	0.336	0.404	0.310	0.431	0.446
Calaveras River @ RR u/s West Lane	4	3/15/03	2/26/04	0.110	0.144	0.144	0.137	0.193
French Camp Slough d/s Airport Way	5	1/28/02	2/26/04	0.063	0.127	0.142	0.143	0.193
Marsh Creek @ Hwy 4	7	3/15/03	2/2/04	0.090	0.224	0.255	0.237	0.323
Morrison Creek @ Franklin	1	1/28/02	1/28/02	0.102	0.102	0.102	0.102	0.102
Mosher Creek @ Morada Lane [(d)]	1	3/15/03	3/15/03	0.028	0.028	[(d)]	0.028	0.028
Ulatis Creek near Main Prairie Rd	6	1/28/02	2/26/04	0.004	0.172	0.240	0.180	0.322

(a) For the large tributary inputs, methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads; the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The methylmercury concentration data are provided in Appendix L. The monthly average concentrations and flows are listed in Appendix F. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.2. Sampling on the small tributaries and Cache Creek Settling Basin did not take place monthly, and flow gages were unavailable for the small tributaries. All available methylmercury concentration data were averaged to estimate annual average methylmercury concentrations and loads for the Cache Creek Settling Basin, and wet weather methylmercury concentration data were averaged to estimate annual average methylmercury concentrations and loads for the small tributaries.

(b) The average of monthly average concentrations for Sacramento River at Colusa for months when Fremont Weir spilled during WY2000-2003 (January, February, March, May, and December) is shown in parentheses.

(c) Only six Prospect Slough MeHg sampling events took place when there was a net outflow. These sampling events are described in parentheses. Methylmercury concentrations during other times were strongly affected by tidal pumping of waters from the Sacramento River.

(d) The one Mosher Creek sample result was combined with the Bear Creek methylmercury data to estimate methylmercury loads for both creeks.

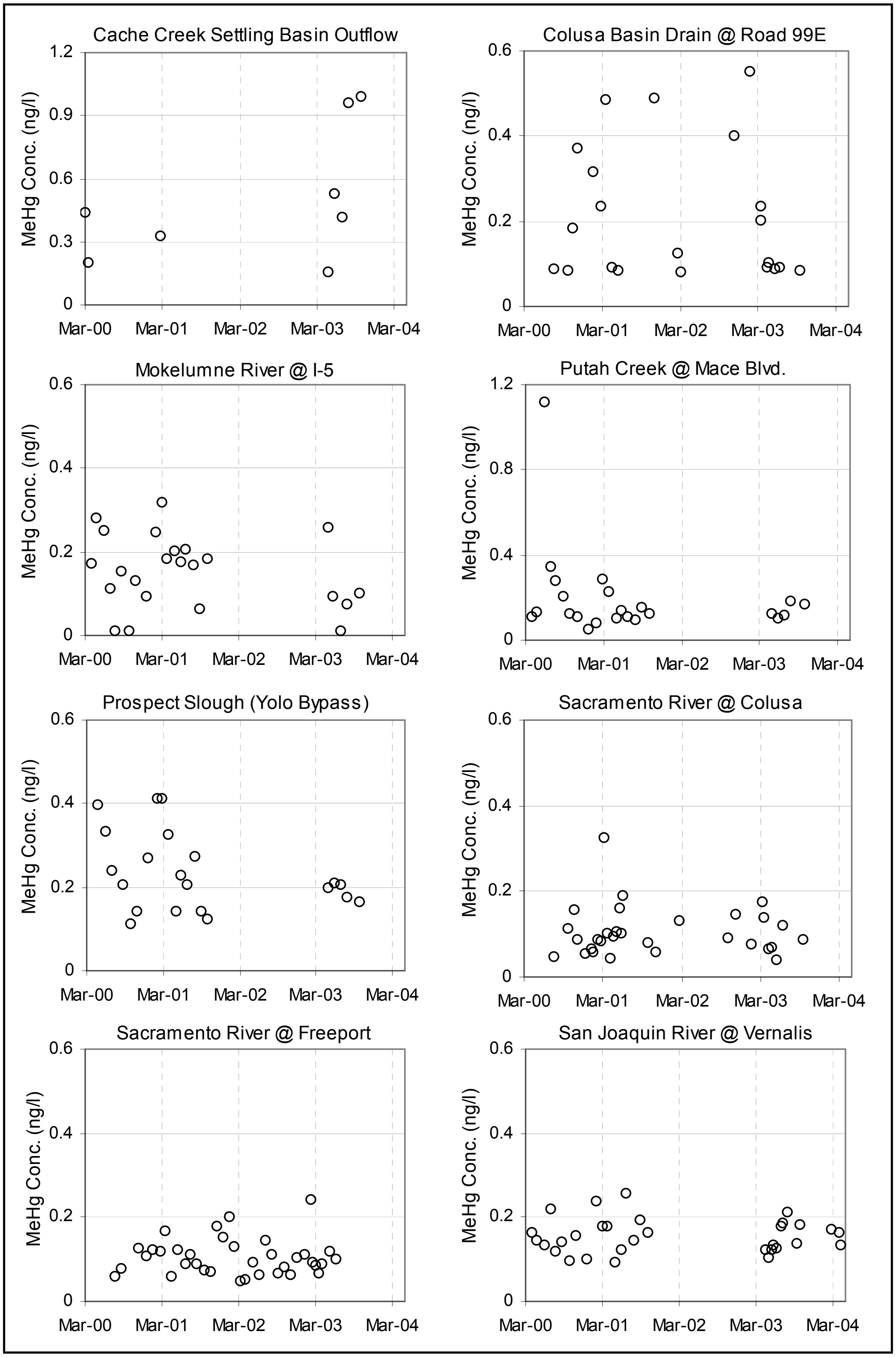

Figure 6.3a: Methylmercury Concentrations for Major Tributary Inputs

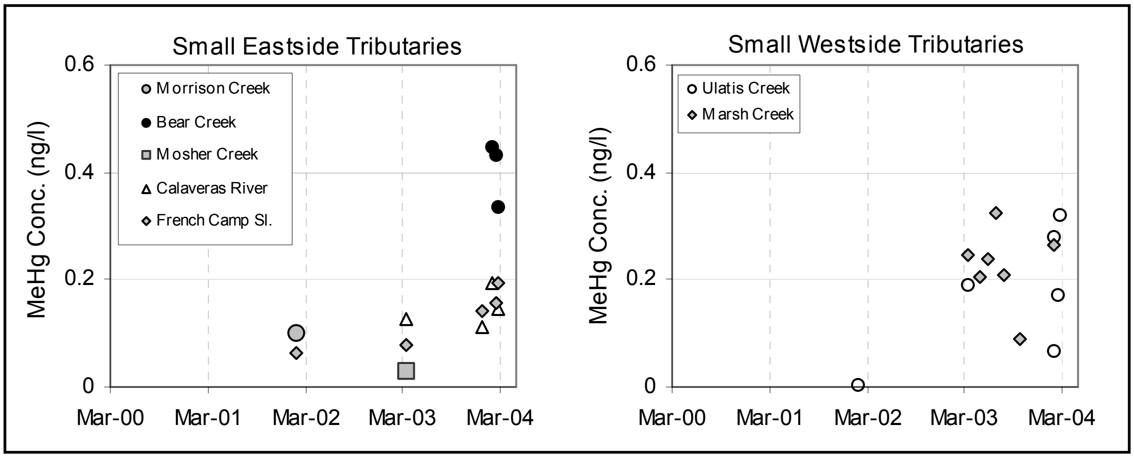

Figure 6.3b: Methylmercury Concentrations for Small Tributary Inputs

6.2.2 Within-Delta Sediment Flux

Methylmercury flux from within-Delta sediments is estimated to contribute about 36% of the overall methylmercury load (Table 6.2). Methylmercury loads from bottom sediment in open water were estimated from flux rates measured by Gill and others (2003). Wetland flux rates were from Heim, Sassone and others (Heim *et al.*, 2004; Sassone *et al.*, 2004) and a load calculation method outlined by Heim and others (Heim, 2004; Heim *et al.*, 2004). To measure methylmercury flux in open water habitats, Gill and others (2003) deployed benthic flux chambers at nine locations in the Bay-Delta region during five separate field-sampling efforts between May 2000 and October 2001. This study estimated a methylmercury flux rate of approximately 10 ng/m^2/day for open water habitat. An additional study of sediment-water MeHg flux within marsh and wetland habitat was conducted at two experimental ponds on Twitchell Island (Heim *et al.*, 2004; Sassone *et al.*, 2004). The west pond, which had more shallow water and greater coverage of emergent vegetation, had sediment-water flux rates of 41 ng/m^2/day during June 2003, while the flux from the east pond had a flux rate of 3 ng/m^2/day. In October 2003, the flux from both ponds decreased to 3 ng/m^2/day. Heim (2004) recommended that the flux rates for the west pond be used to estimate warm and cool season loads; the warm season was defined as March through September (214 days) and the cool season as October through February (151 days).

Wetland and open water acreages were estimated using the 2006 National Wetland Inventory coverage for the Delta region (USFWS, 2006; Figure 6.4). Types of wetland habitat in the Delta and Yolo Bypass are predominantly seasonal wetlands and tidal, salt, brackish and freshwater marshes. The open-water, warm season wetland and cool season wetland flux rates were multiplied by the open water and wetland areas, respectively, to estimate daily loading. The daily loads were multiplied by the number of days in the warm and cool seasons and then summed to estimate annual loading. The loads to each Delta subarea were calculated (Table 6.4) to develop subarea-specific allocations (Chapter 8). The Yolo Bypass subarea has the greatest methylmercury loading from sediment because it has the greatest acreage of wetlands; the Central Delta subarea is second because it has the greatest amount of open water habitat. Methylmercury loading from wetland and open water sediments in each subarea was summed so that the Delta-wide methylmercury loading from sediments could be compared with other sources in Table 6.2.

Using the Twitchell Island west pond summer flux rates, methylmercury loading from wetlands in the Delta/Yolo Bypass accounts for about 19% of all methylmercury to the Delta. However, if the east pond data had been used, methylmercury loading from wetlands would account for only about 3% of all methylmercury to the Delta. This illustrates the need for better characterization of wetlands throughout the Delta. Research elsewhere in California and the United States has found that wetlands are sites of efficient methylmercury production (Slotton *et al*., 2003; Heim *et al*., 2003; St. Louis *et al*., 1994, 1996; Gilmour *et al.*, 1998), so much so that one of the best predictors of methylmercury concentrations in water and in biota is the amount of wetland present in upstream watersheds (Krabbenhoft *et al.*, 1999; Wiener *et al.*, 2003b). Until additional research has been conducted in the Delta and Yolo Bypass, the Twitchell Island west pond summer flux rates will be used to estimate methylmercury loading from wetlands for the TMDL.

As described in Section 3.5, several wetland studies are underway in the Bay-Delta region. Texas A&M University, Moss Landing Marine Laboratory, CDFG and Central Valley Water Board are conducting additional loading studies to better define methylmercury sediment flux rates from different types of wetlands, open water, floodplain and other habitats in the Delta, Yolo Bypass and their tributary watersheds. The results of these studies should be available in 2008. However, additional studies will be needed to evaluate methylmercury management practices.

Space intentionally left blank.

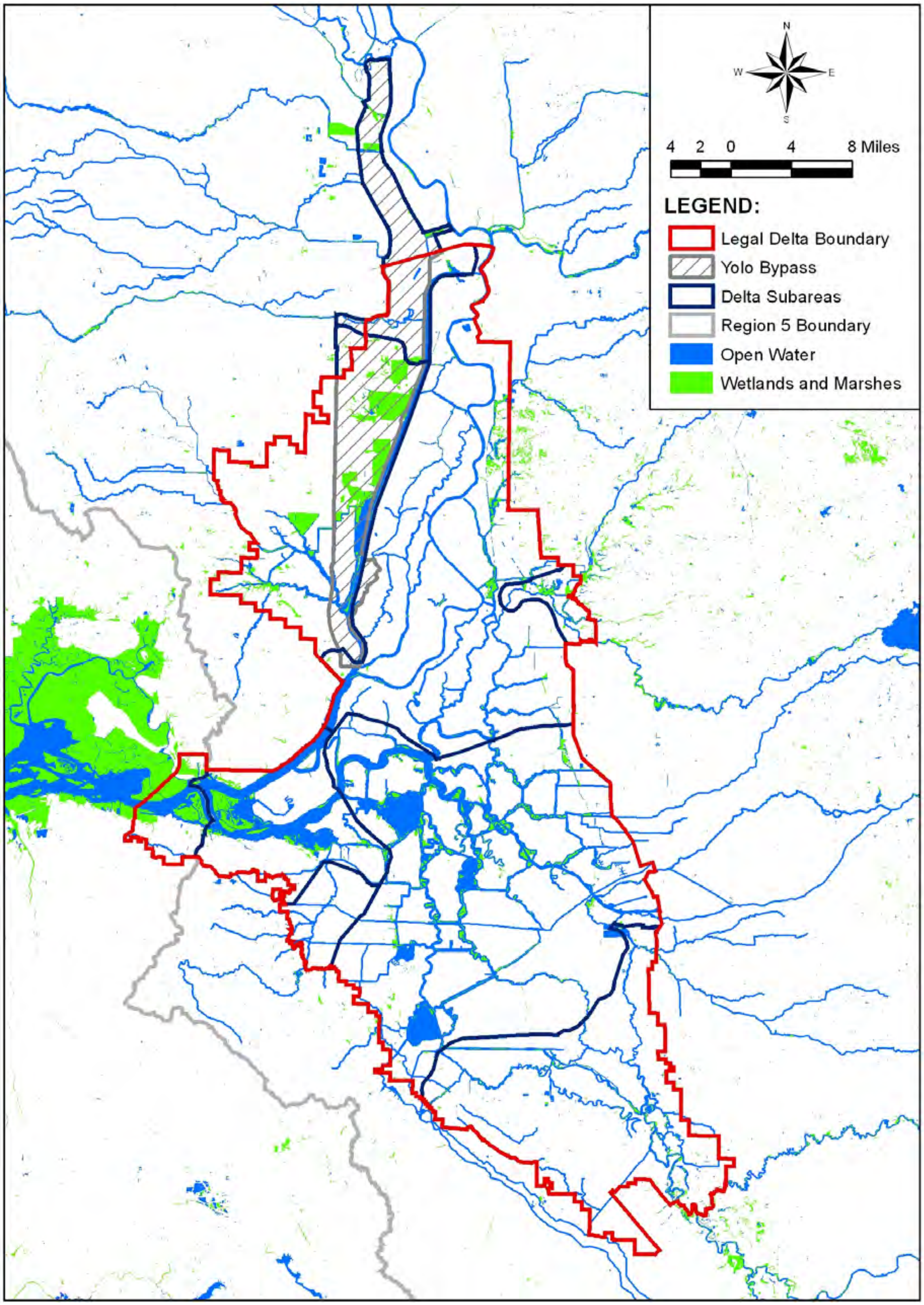

Figure 6.4: Delta and Yolo Bypass Wetlands and Open Water Habitat. Wetland areas include seasonal wetlands and brackish and freshwater marshes. (Wetland and open water acreage: USFWS, 2006.)

Table 6.4: Methylmercury Loading from Wetland and Open Water Habitats in Each Delta Subarea. [a]

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North [d]	Yolo Bypass-South	Grand Total
Open Water Habitats									
Open Water (acres):	25,141	271	12.0	9,483	3,246	13,118	1,281	5,709	58,261
% of Total Water Area:	43%	0.47%	0.02%	16%	5.6%	23%	2.2%	10%	100%
Open Water (m^2):	101,743,759	1,096,558	48,501	38,375,389	13,136,719	53,088,806	5,185,613	23,102,662	235,778,006
Daily Open Water MeHg Load (g/day) [b]:	1.02	0.0110	0.0005	0.38	0.13	0.53	0.052	0.23	2.4
Annual Open Water MeHg Load (g/year):	371	4.0	0.18	140	48	194	19	84	861
Wetland Habitats [c]									
Wetland Area (acres):	5,594	803	9.2	2,538	1,170	3,609	1,577	11,276	26,576
% of Total Wetland Area:	21%	3.0%	0.03%	9.6%	4.4%	14%	5.9%	42%	100%
Wetland Area (m^2):	22,636,361	3,250,048	37,399	10,272,237	4,735,497	14,605,419	6,382,048	45,632,423	107,551,433
Warm Season MeHg Daily Load (g/day):	0.92	0.13	0.0015	0.42	0.19	0.59	0.26	1.9	4.4
Cool Season MeHg Daily Load (g/day):	0.068	0.010	0.00011	0.031	0.014	0.044	0.019	0.14	0.32
Annual Wetland MeHg Load (g/year):	207	29.7	0.34	94	43	134	58	417	983
Annual MeHg Load (grams/year):	**578**	**34**	**0.52**	**234**	**91**	**327**	**77**	**501**	**1,844**

(a) Wetland and open water habitat acreages were obtained from the National Wetland Inventory (USFWS, 2006).

(b) The daily open water MeHg load for each Delta subarea was estimated by multiplying its open water area by the open water sediment flux rate, 10 ng/m2/day. The open water MeHg flux rate was developed by Gill and others using benthic flux chambers (Gill *et al.*, 2003).

(c) The daily warm season and cool season wetland MeHg loads for each Delta subarea were estimated by multiplying the open water area by the warm and cool season wetland flux rates, 41 ng/m2/day and 3 ng/m2/day. The warm and cool season wetland flux rates were developed by Heim and others (2004) using direct measurement of MeHg concentrations in inflows and outflows from test wetlands on Twitchell Island in the west Delta. The warm season for the wetland flux rate is defined approximately as March through September (214 days) and the cool season is defined approximately as October through February (151 days) (Heim, 2004). The annual load was estimated by multiplying the number of days in the warm and cool seasons by the daily warm and cool season loads, respectively, and summing the resulting seasonal loads.

(d) The Yolo Bypass-North subarea includes wetland and open water areas in the Yolo Bypass north of the legal Delta boundary.

6.2.3 Municipal & Industrial Sources

Twenty-one NPDES-permitted municipal and industrial dischargers are located in the Delta (Figure 6.5, Table 6.5). These facility discharges account for about 4% (204 g/yr) of the annual methylmercury loading to the Delta (Table 6.2). Information on the facilities is from the State Water Resources Control Board's Surface Water Information (SWIM) database. Information on average discharge rates for each facility was obtained from the Central Valley Water Board's discharger project files and permits.

As described in Sections 6.2.1 and 6.3.1, the WY2000-2003 period encompasses the available methylmercury concentration data for the major Delta tributary inputs and exports. However, only one NPDES-permitted discharger collected effluent methylmercury data during this period. Between December 2000 and June 2003, the Sacramento Regional County Sanitation District (SRCSD) collected 60 samples to characterize its effluent methylmercury levels. In February and March 2004, Central Valley Water Board staff conducted two sampling events at four municipal wastewater treatment plants (WWTPs) to determine whether the SRCSD data are representative of other municipal wastewater treatment plants' effluent methylmercury levels. The 2004 sampling results indicated that the methylmercury data from the SRCSD facility may not be representative of other facilities in the Delta region. Therefore, the Central Valley Water Board issued a California Water Code Section 13267 order in July 2004 requiring municipal WWTPs and other dischargers located in the Delta and downstream of major dams in the Delta's tributary watersheds to monitor and characterize their effluent. Table 6.5 summarizes the results of available methylmercury data for facility discharges in the Delta. Table G.3 in Appendix G provides a summary of the methylmercury data generated by NPDES facility sampling efforts throughout the Delta region. A detailed review of the data is provided in the Central Valley Water Board staff report, *A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley* (Bosworth *et al.*, 2008), along with a copy of the letter and a list of facilities that received the Section 13267 order and a summary of all available methylmercury data for facility discharges to the Delta and its tributary watersheds. Appendix L of this report provides the available data for facilities within the legal Delta boundary and Yolo Bypass.

Fifteen of the facilities in the Delta/Yolo Bypass are municipal wastewater treatment plants. Average annual methylmercury load for SRCSD's Sacramento River WWTP was calculated using the average effluent methylmercury concentrations observed between December 2000 and June 2003 and the average annual discharge volume for WY2001-2003 (October 2000 through September 2003). Average annual methylmercury loads were calculated for all other municipal WWTPs using the average effluent methylmercury concentrations based on available data collected between August 2004 and October 2005 and the annual discharge volume for WY2005 (October 2004 through September 2005). Facility-specific average effluent methylmercury concentrations ranged from less than 0.02 ng/l (Brentwood and Deuel Vocational Institute WWTPS) to 2.2 ng/l (SRCSD Walnut Grove WWTP).

The variability in the methylmercury concentrations observed in effluent from different municipal WWTPs in the Delta is comparable to WWTP effluent concentrations observed elsewhere. Sampling at the San Jose/Santa Clara Water Pollution Control Plant in California indicated an average effluent methylmercury concentration of 0.04 ng/l (SJ/SC, 2007). A study that evaluated methylmercury concentrations in three domestic sewage treatment plants at the City of Winnipeg, Canada, found average effluent methylmercury concentrations to be very low at two facilities (0.13 to 0.56 ng/l, no seasonal trend) and higher at a third (greater than 2 ng/l, with highest concentrations in the summer) (Bodaly *et al*., 1998). A separate study that evaluated seasonal patterns in sewers and wastewater unit processes in the Onondaga County Metropolitan Wastewater Treatment Plant in Syracuse, New York, observed a mean methylmercury concentration (± standard deviation) of 1.63 ± 1.19 and 1.43 ± 0.67 ng/l in warm and cool months, respectively; a peak of 3.70 ng/l was measured in May (McAlear, 1996). Additional information about facilities elsewhere in California and the United States is provided in "*A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley*" (Bosworth *et al.*, 2008).

Some type of seasonal or other treatment-related variability was observed in effluent methylmercury concentrations at several of the municipal WWTPS in the Delta and its tributary watersheds (Bosworth *et al.*, 2008). Identifying the reasons why some facilities discharge effluent with higher methylmercury concentrations than others, and why some facilities have seasonal or other treatment-related variability in their methylmercury discharges, could be critical components to the development of methylmercury controls.[35]

The City of Sacramento owns and operates a combined sewer system (CSS) that serves about eleven thousand acres. The CSS conveys up to 60 mgd of domestic and industrial wastewater and storm runoff to the SRCSD's Sacramento River WWTP. The City of Sacramento operates its Combined Wastewater Treatment Plant (CA0079111) only when combined wastewater/storm flows exceed 60 mgd (Table G.2 in Appendix G). The plant provides primary treatment with disinfection. The CSS discharges to receiving waters only when storm flows exceed total treatment and storage capacity. Discharges are predominantly urban storm runoff. No methylmercury data are available yet for the plant or untreated CSS discharges. Therefore, the average methylmercury concentration in wet weather urban runoff (0.241 ng/l, see Section 6.2.5) and average annual discharge volume (467 million gallons/year, see Table G.2b) were used to estimate a CSS methylmercury load of 0.43 g/yr.

The Oakwood Lake Subdivision Mining Reclamation (CA0082783; formerly known as the Manteca Aggregate Sand Plant) allows flood-control pumping from Oakwood Lake, a former excavation pit filled primarily by groundwater, to the San Joaquin River. The results from

---

[35] In addition, seasonal increases in effluent methylmercury loading from some facilities could result in a greater influence on local water bodies, especially during the dry season. For example, SRCSD Sacramento River WWTP (the largest permitted facility discharge in the Central Valley) has an annual effluent methylmercury load (161 g/yr, see Table 6.5) that averages about 8% of its receiving water load (2,026 g/yr, Sacramento River at Freeport, see Table 6.2). Between December 2000 and September 2003 (the TMDL Period), SRCSD daily effluent loads during the wet seasons (e.g., December to April) ranged between 1 and 7% of river loads, and daily effluent volumes averaged about 2% of river volume (Bosworth *et al.*, 2008). However, during the dry season, SRCSD daily effluent loads ranged between about 10 and 35% of river loads while effluent volume remained about 2% of river volume. Currently, little is known about the seasonal exposure regime controlling methylmercury concentrations in aquatic biota. Therefore, this TMDL is based on annual average source loads to weight all seasons equally. However, studies are planned to better determine the seasonal exposure regime when most of the methylmercury is sequestered in the aquatic food chain; results from these studies may lead to future revisions in the TMDL. Seasonal discharge information is not yet available for most methylmercury sources to the Delta, but would be required by the source control and characterization studies proposed by the draft implementation plan described in Chapter 4 of the Proposed Basin Plan Amendment draft staff report.

discharge sampling in August and November 2004, nondetect (<0.02 ng/l) and 0.043 ng/l respectively, are comparable to groundwater treatment plant discharges in the Delta's tributary watersheds (refer to Table G.3 in Appendix G) and are substantially lower than the monthly average methylmercury concentrations observed in the San Joaquin River at Vernalis between August and December (0.102 to 0.167; refer to Table F.1 in Appendix F). Average annual methylmercury loading from Oakwood Lake was estimated using a methylmercury concentration of 0.03 ng/l and the average annual discharge volume.

Three of the facilities in the Delta are power or heating/cooling facilities: GWF Power Systems (CA0082309), Mirant Delta LLC Contra Costa Power Plant (CA0004863), and the State of California Central Heating/Cooling Plant (CA0078581). Two of these facilities use ambient water for cooling water. Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G and Bosworth *et al.*, 2008), such facilities do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available (see Section 7.1.2). GWF Power Systems (CA0082309) acquires its intake water from sources other than ambient surface water; adequate data were available to estimate the methylmercury load in its discharge.

The Metropolitan Stevedore Company (CA0084174) operates a marine bulk commodity terminal on leased land at the Port of Stockton. Storm water runoff, dust suppression water, and wash down water from bulk materials handling operations collect in a primary retention basin and some other low areas onsite, and evaporate or percolate into groundwater. Discharges may occur during intense storm events or when annual accumulated rainfall far exceeds the average for a given year. Methylmercury concentrations and loads in non-storm water discharges will be evaluated once the Metropolitan Stevedore Company completes methylmercury monitoring.

Space intentionally left blank.

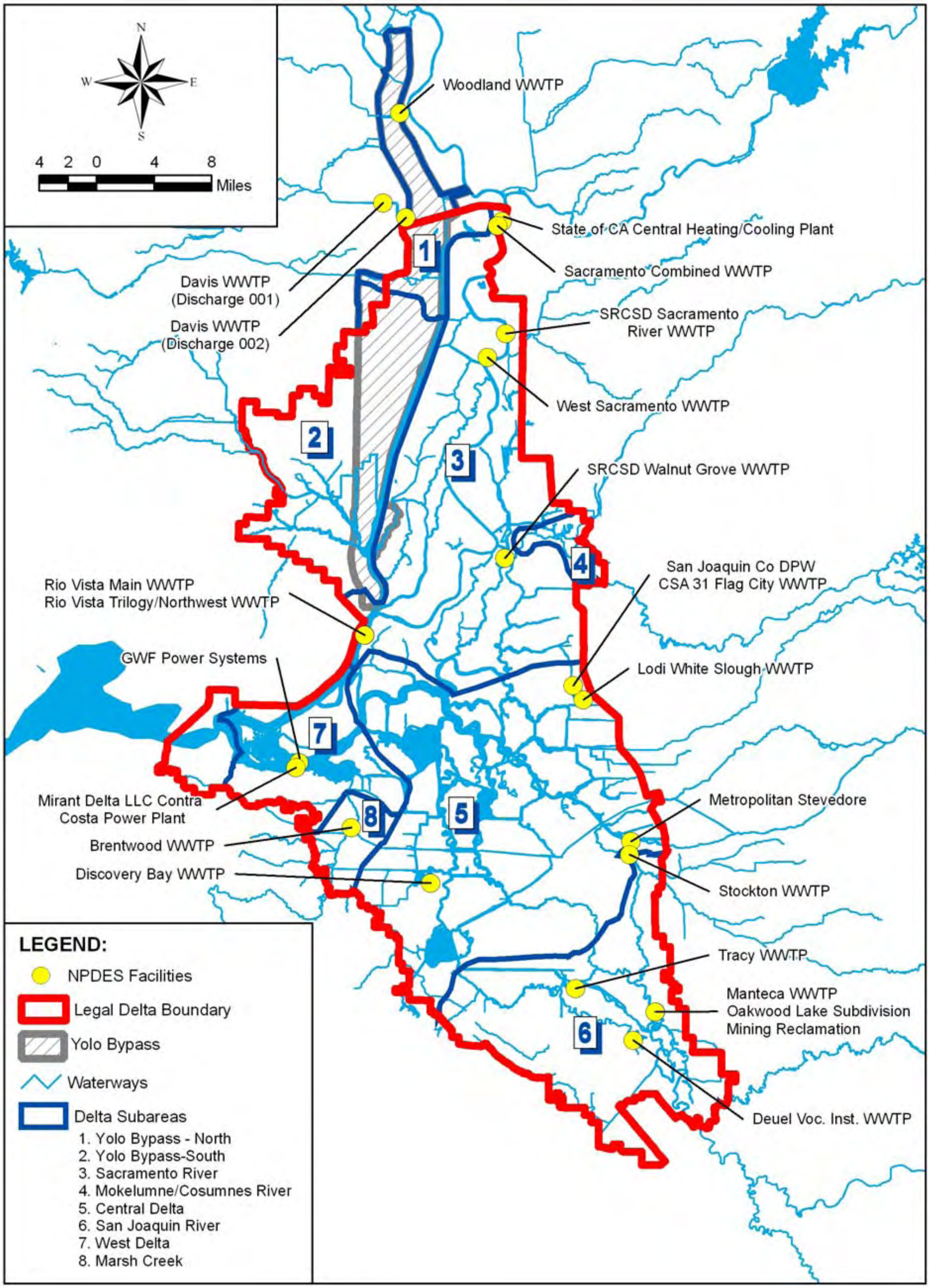

Figure 6.5: NPDES Facilities that Discharge to the Statutory Delta Boundary and Yolo Bypass.

Table 6.5: Summary of Unfiltered Methylmercury Concentration Data for Effluent from NPDES-permitted Facilities That Discharge to the Delta and Yolo Bypass North of the Delta.

Facility Name [(a)]	**NPDES #**	**Facility Type**	**Delta Subarea**	**# of MeHg Sampling Events**	**Average MeHg Conc.** (ng/l) [(b)]	**MeHg Conc. Range** (ng/l)	**# of Nondetect Results**	**MeHg Sampling Period**	**Average Daily Discharge for WY2005** (mgd)	**Annual MeHg Load** (g/yr)
Brentwood WWTP	CA0082660	Mun. WWTP	Marsh Ck	13	0.02 (ND) [(b)]	All ND [(b)]	13	8/04-8/05	3.1	0.086
Davis WWTP (Discharge 001) [(g)]	CA0079049	Mun. WWTP	Yolo Bypass	7	0.55	0.305-1.04	0	8/04-1/05, 7/05	2.8	1.3
Davis WWTP (Discharge 002) [(g)]	CA0079049	Mun. WWTP	Yolo Bypass	5	0.61	0.247-1.44	0	2/05-6/05	2.4	0.78
Deuel Vocational Institute WWTP [(e)]	CA0078093	Mun. WWTP	San Joaquin	3	0.02 (ND)	All ND	3	1/05-6/05	0.47	0.013
Discovery Bay WWTP	CA0078590	Mun. WWTP	Central	13	0.18	ND-2.03	8	8/04-8/05	1.5	0.37
GWF Power Systems	CA0082309	Power	West	4	0.03 (ND)	All ND	4	8/04-5/05	0.05	0.0019
Lodi White Slough WWTP [(f)]	CA0079243	Mun. WWTP	Central	10	0.15	ND-1.24	3	9/04-6/05	4.5	0.93
Manteca WWTP	CA0081558	Mun. WWTP	San Joaquin	11	0.22	0.037-0.356	0	9/04-7/05	4.6	1.4
Mirant Delta LLC Contra Costa Power Plant (Outfall 1)	CA0004863	Power	West	12	0.07	ND-0.121	1	2/04-5/05	2.90	(c)
Mirant Delta LLC Contra Costa Power Plant (Outfall 2)	CA0004863	Power	West	10	0.09	0.042-0.15	0	2/04-3/05	121.03	(c)
Oakwood Lake Subdivision Mining Reclamation [(d)]	CA0082783	Lake Dewatering	San Joaquin	2	0.03	ND-0.043	1	8/04-11/04	9.15	0.38
Rio Vista WWTP	CA0079588	Mun. WWTP	Sacramento	4	0.16	0.035-0.522	0	8/04-4/05	0.47	0.10
Rio Vista Trilogy/Northwest WWTP [(i)]	CA0083771	Mun. WWTP	Sacramento						0.10 / 1.0	(i)
San Joaquin Co DPW CSA 31 Flag City WWTP	CA0082848	Mun. WWTP	Central	3	0.08	ND-0.152	1	1/05-10/05	0.06	0.0066
SRCSD Sacramento River WWTP	CA0077682	Mun. WWTP	Sacramento	60	0.72	0.118-1.64 [(h)]	0	12/00-6/03	162 [(h)]	161
SRCSD Walnut Grove WWTP [(e)]	CA0078794	Mun. WWTP	Sacramento	2	2.2	0.949-3.36	0	1/05-4/05	0.08	0.24
State of California Central Heating/Cooling Plant	CA0078581	Heating /Cooling	Sacramento	4	0.01	ND-0.029	3	8/04-6/05	5.26	(c)
Stockton WWTP	CA0079138	Mun. WWTP	San Joaquin	12	0.94	ND-2.09	1	8/04-7/05	28	36
Tracy WWTP	CA0079154	Mun. WWTP	San Joaquin	13	0.14	ND-0.422	1	8/04-8/05	9.5	1.8
West Sacramento WWTP	CA0079171	Mun. WWTP	Sacramento	12	0.05	ND-0.085	1	8/04-7/05	5.6	0.39
Woodland WWTP	CA0077950	Mun. WWTP	Yolo Bypass	12	0.03	ND-0.059	2	8/04-7/05	6.05	0.25

Table 6.5 Footnotes:

(a) No methylmercury data are yet available for Metropolitan Stevedore (CA0084174), a marine bulk commodity terminal in the Central Delta subarea, and the Sacramento Combined WWTP (CA0079111) in the Sacramento River subarea.

(b) ND: nondetect (below method detection limit). Analytical method detection limits were 0.025 ng/l or less. One half the detection limit was used for nondetect values to calculate the average methylmercury concentrations and loads, except when a facility reported all nondetect values ("All ND"), in which case the detection limit was used to calculate loads.

(c) Based on the comparison of the available intake and outfall methylmercury data (Table G.4 in Appendix G), power and heating/cooling facilities that use ambient water for cooling water do not appear to act as a source of new methylmercury to the Delta. This assumption will be re-evaluated as additional information becomes available.

(d) The Oakwood Lake Subdivision Mining Reclamation was formerly known as the Manteca Aggregate Sand Plant.

(e) Results for the following facilities and sample dates were not incorporated in the summary calculations due to sample preservation hold times exceeding USEPA recommendations: Deuel Vocational Institute WWTP (26 October 2004, <MDL) and SRCSD Walnut Grove WWTP (29 December 2004, 0.759 ng/l).

(f) Lodi White Slough WWTP sampled effluent when discharging to land and to surface water. Only samples collected when the plant discharged to surface water (September 2004 through June 2005) were used in the summary. Effluent that was reclaimed in August 2004 and July 2005 had methylmercury concentrations of 0.054 ng/l and <0.020, respectively.

(g) The City of Davis WWTP (CA0079049) has two seasonal discharge locations; wastewater is discharged from Discharge 001 to the Willow Slough Bypass upstream of the Yolo Bypass and from Discharge 002 to the Conaway Ranch Toe Drain in the Yolo Bypass. The Discharge 001 methylmercury load is based on effluent volumes for October 2004 through January 2005 plus July 2005 through September 2005. The Discharge 002 methylmercury load is based on effluent volumes for February 2005 through June 2005.

(h) The SRCSD Sacramento River WWTP (CA0077682) methylmercury concentration data was collected between December 2000 and June 2003. Two data points failed SRCSD's Quality Assurance review (7/13/2001: 2.93 ng/l, 6/18/2006: 0.08 ng/l); these data are not included in the TMDL calculations. Average daily discharge is based on average monthly flows during WY2000-2003.

(i) The City of Rio Vista's Trilogy WWTP was replaced by the Northwest WWTP, which began discharging to the Sacramento River subarea in 2007 under the same NPDES permit (CA0083771). The Northwest WWTP has a startup dry weather discharge of 1 mgd and peak discharge of 3 mgd. No effluent methylmercury concentration data were available for either the Trilogy or Northwest WWTPs, and no effluent total mercury concentration data were available for the Northwest WWTP, at the time the Delta methylmercury TMDL was developed. The Northwest WWTP effluent methyl and total mercury loads will be determined once it completes one year of monthly monitoring of its discharge.

6.2.4 Agricultural Return Flows

More than half a million acres of the Delta islands are under agricultural production (Figure 6.6). Water seeps and is diverted onto the islands for irrigation from the surrounding river channels. The unused water is returned to Delta waterways via a series of main drains. Many of the islands are predominately peat, a substance that Gill and others (2003) and Heim and others (2003) have shown to be a good substrate for methylmercury production. Water samples collected from five Delta Island main drains in June and July 2000 suggest that the agricultural islands are net exporters of unfiltered methylmercury (Foe, 2003). Methylmercury concentrations were variable but high compared to concentrations in the river channels surrounding the islands from which the irrigation supply water was diverted and unused tail-water returned. Agricultural return flow concentrations averaged 0.35 ng/l in June and July 2000 while concentration in the supply water was 0.07 ng/l; this translates to a net production rate of approximately 17 to 35 grams per month (~0.5 to 1.1 g/day) if occurring over the entire Delta or 10 to 25% of all river loading in the two-month period (Foe, 2003).

The annual methylmercury load from agricultural lands located in the Delta was estimated to be 123 g/yr (Table 6.2). Delta agricultural diversion and return flow estimates were obtained from the Delta Island Consumptive Use Model for water year 1999, the year during which the majority of agricultural drain methylmercury data were collected (Table 6.8); these flow estimates do not include the Yolo Bypass area north of the legal Delta. The annual diversion and return flow water volumes were multiplied by their respective methylmercury concentrations to estimate annual loads. For this preliminary evaluation, the average of available agricultural drain methylmercury data (Tables 6.6 and 6.7) was used to estimate methylmercury concentrations in all Delta agricultural return flows. The methylmercury concentration of river diversions was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations between May and December (Appendix D, Table D.3). To estimate the methylmercury loading from agricultural lands, the estimated methylmercury load in the river waters diverted onto the islands was subtracted from the agricultural return loads (Table 6.6), resulting in a net input of 123 grams per year. This load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate a subarea specific loading rate (Table 6.9). The Central Delta and Sacramento River subareas have the greatest estimated methylmercury loading from agricultural lands because they have the largest acreage of agricultural land.

This evaluation indicates that agricultural runoff within the Delta and Yolo Bypass may contribute about 2.4% of the methylmercury load to the Delta/Yolo Bypass. However, Central Valley Water Board staff recognizes that agricultural loads have not been fully characterized. Staff recommends that a follow-up study be undertaken to more fully monitor and characterize loads from the Delta Islands and upland areas within and upstream of the legal Delta and, if elevated, determine the primary land uses responsible for methylmercury production. The study should be done in cooperation with agricultural interests in the Delta region.

Space intentionally left blank.

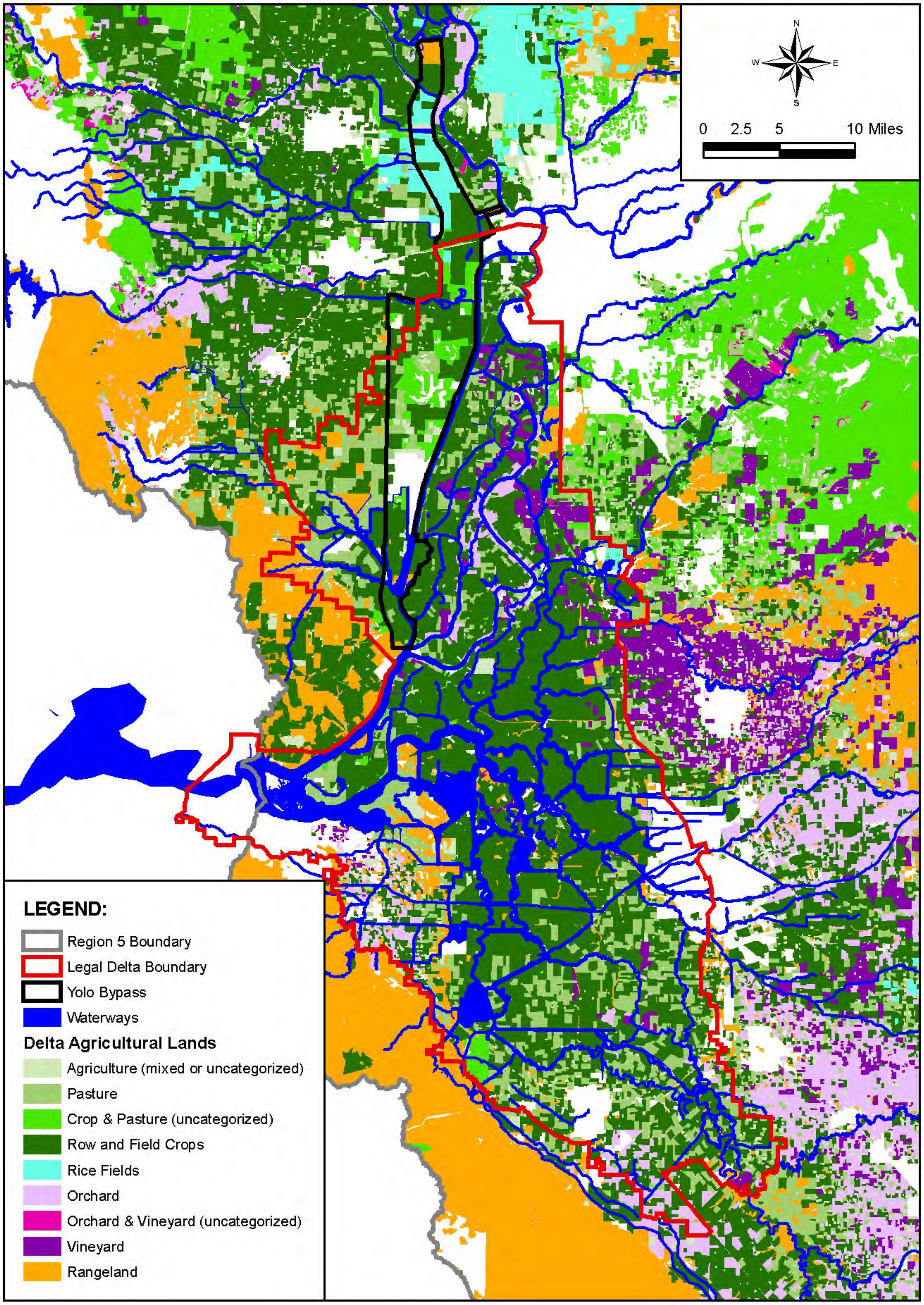

Figure 6.6: Agricultural Lands within the Statutory Delta Boundary and Yolo Bypass.

Table 6.6: Values Used to Estimate MeHg Loads from Agricultural Lands within the Legal Delta Boundary

	Average MeHg Conc. (ng/l) [a]	Flow (acre-feet/ yr) [b]	MeHg Load (g/yr)
Diversions:	0.071	1,597,880	139
Ag Drain Returns:	0.352	603,546	262
Net Ag Drain Input (g/yr):			**123**

(a) Average agricultural drain methylmercury concentration obtained from Table 6.7. Average methylmercury concentration for diversion flows was estimated by averaging monthly Sacramento River and State Water Project MeHg concentrations during May through December (Appendix D).
(b) Estimated annual average agricultural diversion and return flows were obtained from Table 6.8.

Table 6.7: Delta Agricultural Main Drain Methylmercury Concentration Data [a]

Site	Sample Date	MeHg Conc. (ng/l)
Empire Tract Main Drain	6/26/00	0.093
Empire Tract Main Drain	7/19/00	0.117
Lower Jones Main Drain	6/26/00	0.302
Staten Island Main drain	6/26/00	0.198
Staten Island Main drain	7/19/00	0.094
Twitchell Island Main Drain	6/26/00	0.387
Twitchell Island Main Drain	7/19/00	1.500
Twitchell Island Main Drain	6/30/03	0.292 [b]
Twitchell Island Main Drain	7/28/03	0.341
Twitchell Island Main Drain	8/27/03	0.609
Twitchell Island Main Drain	9/25/03	0.157 [b]
Upper Jones Main Drain	7/19/00	0.131

(a) Source: Foe, 2003; Central Valley Water Board sampling, 2003.
(b) Average of laboratory replicates (0.289 and 0.294 ng/l on 6/30/03 and 0.147 and 0.167 ng/l on 9/25/03).

Table 6.8: Delta-wide Island Consumptive Use Estimates – Water Year 1999 (acre-feet)

Period [a]	Diversions + Seepage	Return Flow	Net Channel Depletion
Oct-98	92,969	36,155	56,815
Nov-98	74,202	34,988	39,213
Dec-98	81,348	31,359	49,989
Jan-99 [b]	*42,180*	*111,661*	*-69,481*
Feb-99 [b]	*34,044*	*120,960*	*-86,916*
Mar-99	57,306	43,410	13,896
Apr-99	108,000	46,532	61,468
May-99	193,317	67,944	125,373
Jun-99	273,838	92,648	181,190
Jul-99	353,800	120,147	233,653
Aug-99	221,540	77,167	144,373
Sep-99	141,560	53,197	88,364
Annual Totals [b]	**1,597,880**	**603,546**	**994,334**

(a) Diversion and return flow volumes were obtained from the Delta Island Consumptive Use Model (Suits, 2000).
(b) Only months with positive depletion were used in the annual methylmercury load estimates because no methylmercury concentration data were available for the agricultural return drains during the coolest/wettest months.

Table 6.9: Agricultural Acreage and Methylmercury Load Estimates by Delta Subarea

	Central Delta	Cosumnes / Mokelumne River	Marsh Creek	Sacramento River	San Joaquin River	West Delta	Yolo Bypass-North [c]	Yolo Bypass-South	TOTAL
Acreage [a]	157,035	6,790	9,362	155,532	96,874	17,313	11,046	70,523	**524,474**
% of Total Acreage	30%	1.3%	1.8%	30%	18%	3.3%	2.1%	13%	**100%**
Estimated Annual MeHg Load (g/year) [b]	36.8	1.6	2.2	36.4	22.7	4.1	2.6	16.5	**123**

(a) Land cover source: DWR land use GIS coverages (1993-2003).

(b) A Delta-wide agricultural land methylmercury loading of 123 g/yr was estimated using the information presented in Tables 6.6 through 6.8. The Delta-wide load was multiplied by the percentage of total agricultural acreage located in each Delta subarea to estimate the amount of loading from agricultural lands in each subarea.

(c) The Yolo Bypass-North subarea does not include agricultural areas in the Yolo Bypass north of the legal Delta boundary.

6.2.5 Urban Runoff

Approximately 60,000 acres of the land in the Delta and Yolo Bypass north of the legal Delta boundary is classified as urban (DWR, 1993-2003). Most of the urban area is regulated by waste discharge requirements under the National Pollutant Discharge Elimination System (NPDES), which permits discharge of storm water from municipal separate storm sewer systems (MS4s). [36] Table 6.10 lists the permits that regulate urban runoff in the Delta and the amount of urban acreage in each Delta subarea. Figure 6.7 shows their locations. Urban acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available MS4 service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city and county boundaries. Urban areas not encompassed by a MS4 service area were grouped into a “nonpoint source” category within each Delta subarea.

Methylmercury concentration data have been collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways in or adjacent to the Delta. Figure 6.8 shows the sampling locations, Figure H.1 in Appendix H illustrates the wet and dry weather concentrations by location, and Appendix L provides the concentration data used in Figure H.1. Methylmercury concentrations ranged from a wet weather low of 0.035 ng/l (City of

[36] A municipal separate storm sewer system (MS4) is a conveyance or system of conveyances that include roads with drainage systems, municipal streets, alleys, catch basins, curbs, gutters, ditches, manmade channels, or storm drains, owned by a State, city, county, town or other public body. MS4s are designed and used for collecting or conveying storm water and do not include combined sewer systems or parts of a publicly owned treatment works. MS4s discharge to Waters of the United States. The Municipal Storm Water Permitting Program regulates storm water discharges from MS4s. MS4 permits were issued in two phases. Under Phase I, which started in 1990, the RWQCBs have adopted NPDES storm water permits for medium (serving between 100,000 and 250,000 people) and large (serving greater than 250,000 people) municipalities. Most of these permits are issued to a group of co-permittees encompassing an entire metropolitan area. These permits are reissued as the permits expire. As part of Phase II, the State Board adopted a General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ, NPDES No. CAS000004) to provide permit coverage for smaller municipalities, including non-traditional small MS4s, which are governmental facilities such as military bases, public campuses, and prison and hospital complexes.

Sacramento Sump 111) to a dry weather high of 2.04 ng/l (Strong Ranch Slough). A visual inspection of the methylmercury data suggests that the differences between urban watersheds are not related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 6.11). The averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta and were used to estimate loads. These values are similar to methylmercury levels observed during high flow conditions in two urbanized tributaries in the Washington, D.C. region. The urbanized Northeast and Northwest Branches of the Anacostia River had average methylmercury concentrations of 0.12 ± 0.06 ng/l and 0.07 ± 0.07 ng/l, respectively, during base flows, and 0.39 ± 0.21 ng/l and 0.77 ± 0.46 ng/l, during high flows (Mason and Sullivan, 1998).

Average annual urban runoff loading was estimated for WY2000-2003 so that urban runoff loading could be compared to tributary loading (Table 6.2). To estimate wet weather methylmercury loads, the wet weather concentration (0.241 ng/l) was multiplied by the runoff volumes estimated for WY2000-2003 for each MS4 area within each Delta subarea. To estimate dry weather methylmercury loads, the dry weather concentration (0.363 ng/l) was multiplied by the estimated dry weather urban runoff volume. Section E.2.3 in Appendix E describes the methods used to estimate wet and dry weather runoff volumes from urban areas within the Delta. Wet and dry weather methylmercury loads were summed to estimate the average annual loading of 20 grams to Delta waterways. The loading to each Delta subarea (Table 6.12) was used to develop MS4 Permittee and subarea-specific allocations (Chapter 8).

Urban land use comprises a small portion of the surface area in the Delta and contributes only about 0.4% of the Delta methylmercury load (Table 6.2). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – occur within 20 miles of the statutory Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta load estimate. As a result, the urban contribution to the Delta methylmercury load may be underestimated.

To evaluate the potential contributions from upstream urban lands, the methylmercury loadings from the two MS4 service areas with the greatest urban acreage immediately upstream of the Delta were estimated. The sum of methylmercury loads from the Sacramento and Stockton MS4 areas may contribute about 1% of methylmercury loading to the Delta (Table 6.13). These loads are expected to increase as urbanization continues around the Delta.

Table 6.10: Urban Acreage and MS4 Permits that Regulate Urban Runoff within the Delta/Yolo Bypass.

Permittee	NPDES # [a]	Urban Acreage within Delta Subareas [b]							Total Acreage
		Central Delta	Marsh Creek	Mokelumne / Cosumnes Rivers	Sacra-mento River	San Joaquin River	West Delta	Yolo Bypass [c]	
Contra Costa County	CAS083313	2,181	3,427				9,518		15,126
Lathrop (City of)	CAS000004					738			738
Lodi (City of)	CAS000004	134							134
Port of Stockton	CAS084077	1,067				28			1,095
Rio Vista (City of)	CAS000004				37				37
Sacramento Area MS4 [d]	CAS082597				4,766				4,766
San Joaquin County	CAS000004	1,494		121	521	6,040			8,176
Solano County	CAS000004				181			220	401
Stockton MS4 Permit Area	CAS083470	10,574				1,481			12,055
Tracy (City of)	CAS000004					5,268			5,268
West Sacramento (City of)	CAS000004				1,824			2,756	4,580
Yolo County	CAS000004				200			796	966
Urban Nonpoint Source [e]		337		44	1,615	7	231		2,234
Total Acreage		**15,787**	**3,427**	**165**	**9,144**	**13,562**	**9,749**	**3,772**	**55,606**

(a) Permittees with NPDES No. CAS000004 are covered under the General Permit for the discharge of storm water from small MS4s (WQ Order No. 2003-0005-DWQ) adopted by the State Water Board to provide permit coverage for smaller municipalities (serving less than 100,000 people).

(b) Urban land uses and acreages corresponding to each Permittee were estimated from the DWR Land Use coverage (DWR, 1993-2003) using available service area delineations. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city boundaries.

(c) The Yolo Bypass subarea includes urban areas in the Yolo Bypass north of the legal Delta boundary.

(d) The Sacramento MS4 Area does not include the Sacramento Combined Sewer System (CSS) service area illustrated in Figure 6.7. The CSS service area is permitted by a separate NPDES permit, which is described in Section 6.2.3 and Table G.2 in Appendix G.

(e) Urban areas not encompassed by a MS4 service area were grouped into the "nonpoint source" category.

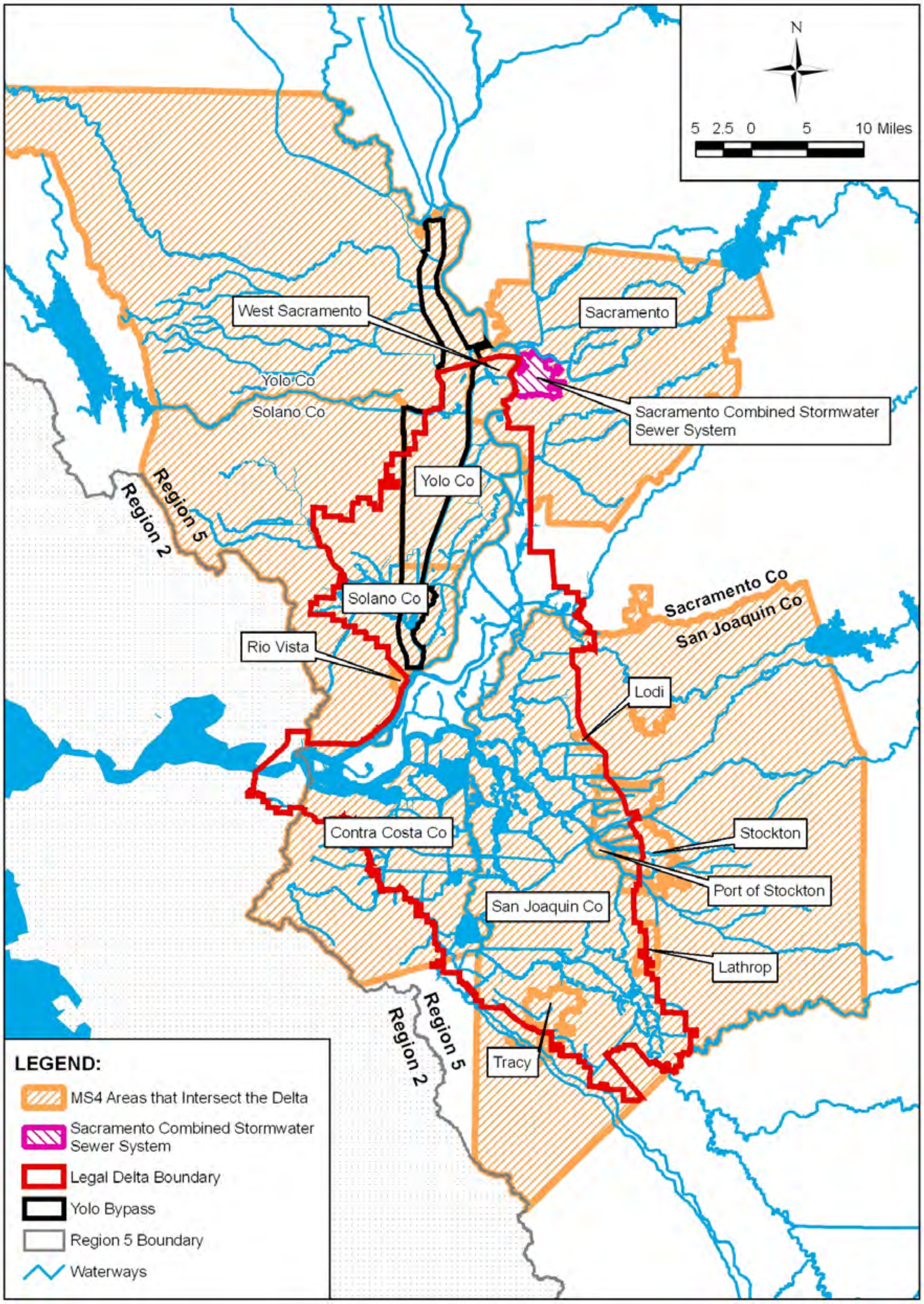

Figure 6.7: NPDES Permitted Municipal Separate Storm Sewer System (MS4) Areas in the Delta Region. (Only those MS4 areas that intersect the statutory Delta boundary and Yolo Bypass are labeled. MS4 service area delineations for Sacramento, Stockton and Tracy are based on paper or electronic maps provided by the MS4 Permittees; all other MS4 service areas were delineated using 1990 city or county boundaries.)

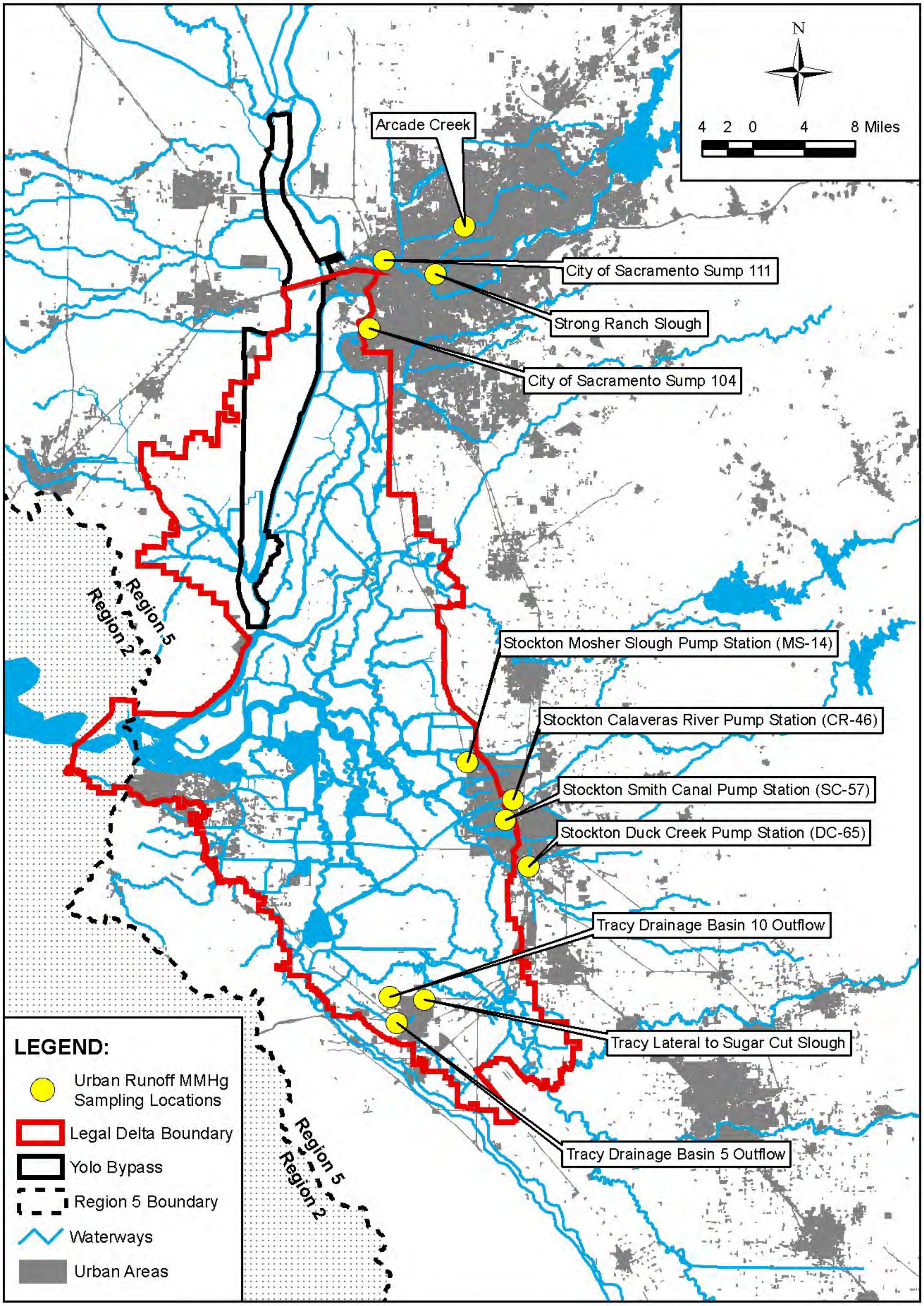

Figure 6.8: Urban Areas and Aqueous MeHg Sampling Locations in the Delta Region.

Table 6.11: Summary of Urban Runoff Methylmercury Concentrations

Location	# of Samples	Minimum Conc. (ng/l)	Average Conc. (ng/l)	Maximum Conc. (ng/l)
DRY WEATHER				
Arcade Creek	9	0.099	0.358	1.213
Sacramento Strong Ranch Slough	2	0.158	1.099	2.040
Sacramento Sump 104	2	0.088	0.093	0.097
Sacramento Sump 111	2	0.135	0.176	0.217
Tracy Lateral to Sugar Cut Slough	1	0.091	0.091	0.091
Average of Location Averages:	**0.363 ng/l**			
WET WEATHER				
Arcade Creek	7	0.099	0.240	0.339
Sacramento Strong Ranch Slough	4	0.237	0.522	0.878
Sump 104	4	0.153	0.290	0.610
Sump 111	4	0.035	0.212	0.420
Stockton Calaveras River Pump Station	5	0.105	0.167	0.301
Stockton Duck Creek Pump Station	1	0.103	0.103	0.103
Stockton Mosher Slough Pump Station	4	0.084	0.125	0.189
Stockton Smith Canal Pump Station	4	0.099	0.263	0.533
Tracy Drainage Basin 10 Outflow	3	0.103	0.192	0.257
Tracy Drainage Basin 5 Outflow	3	0.110	0.138	0.191
Tracy Lateral to Sugar Cut Slough	3	0.040	0.400	0.918
Average of Location Averages:	**0.241 ng/l**			

Table 6.12: Average Annual Methylmercury Loading from Urban Areas within Each Delta Subarea for WY2000-2003

MS4 PERMITEE	DELTA SUBAREA (g/yr)							Grand Total (g/yr)
	Central Delta	Marsh Creek	Mokelumne / Cosumnes Rivers	Sacra-mento River	San Joaquin River	West Delta	Yolo Bypass	
Contra Costa County	0.75	1.2				3.2		**5.2**
Lathrop (City of)					0.27			**0.27**
Lodi (City of)	0.053							**0.053**
Port of Stockton	0.39				0.010			**0.40**
Rio Vista (City of)				0.014				**0.014**
Sacramento Area MS4				1.8				**1.8**
San Joaquin County	0.57		0.045	0.19	2.2			**3.0**
Solano County				0.073			0.085	**0.16**
Stockton MS4 Permit Area	3.6				0.50			**4.1**
Tracy (City of)					1.8			**1.8**
West Sacramento (City of)				0.65			1.1	**1.8**
Yolo County				0.073			0.33	**0.40**
Urban Nonpoint Source	0.14		0.018	0.63	0.0022	0.066		**0.85**
Grand Total	**5.5**	**1.2**	**0.063**	**3.4**	**4.8**	**3.3**	**1.5**	**20**

Table 6.13: Comparison of Sacramento and Stockton Area MS4 Methylmercury Loading to Delta Methylmercury Loading for WY2000-2003.

MS4 Service Area [(a)]	Water Volume (M acre-feet) [(b)]	MeHg Load (grams/year)
Sacramento MS4 Urban Total	0.18	59
Stockton MS4 Urban Total	0.026	8.6
Total Delta Inputs [(c)]	20	5,219
Stockton & Sacramento Runoff as % of Total Delta Inputs	**1.0%**	**1.3%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage in the greater Delta region, with urban land use areas of about 161,000 and 25,000 acres, respectively.

(b) Refer to Section E.2.3 in Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.

(c) These values represent the sum of all tributary inputs and within-Delta methylmercury sources shown in Table 6.2.

6.2.6 Atmospheric Deposition

Atmospheric deposition of methylmercury has not yet been measured within the Delta. However, several published papers provide reviews of methylmercury levels in wet deposition in a variety of locations around the world (e.g., Nguyen *et al.*, 2005; Lawson and Mason, 2001; Mason *et al.*, 1997 and 2000). These reviews indicate that the ratios of methyl to total mercury concentrations in wet deposition range from 0.25 to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. As described in Section 7.1.4 and Table 7.1, total mercury loading from wet deposition to Delta water surfaces and land surfaces not including urban areas was estimated to be 2,318 g/yr for WY2000-2003. A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited by wet deposition:

Equation 6.2:

$$\text{MeHg Mass} = \text{Total mercury mass} * \text{MeHg:TotHg}$$
$$23 \text{ g/yr} = 2.3 \text{ kg/year} * 0.01$$

Table 6.14 provides the methylmercury load estimates for atmospheric deposition to each Delta subarea. Wet deposition in the Delta and Yolo Bypass likely contributes less than 1% of all methylmercury entering the Delta (Table 6.2). Therefore, it is assumed that atmospheric input to waterways and land surfaces within the Delta and Yolo Bypass is not a significant source of methylmercury. Methylmercury in wet deposition to urban land surfaces was not evaluated because it is incorporated in the estimates for loading from urbanized lands described in Section 6.2.5.

Table 6.14: Estimate of Average Annual Methylmercury Loading from Wet Deposition

Delta Subarea	WY2000-2003 Average Annual TotHg Load (g/yr) [a]	Estimated MeHg Load (g/yr) [b]
Central Delta	729	7.3
Marsh Creek	23	0.23
Mokelumne / Cosumnes River	29	0.29
Sacramento River	560	5.6
San Joaquin River	272	2.7
West Delta	237	2.4
Yolo Bypass-North [c]	100	1.0
Yolo Bypass-South	315	3.2
TOTAL	**2,265 (2.3 kg/yr)**	**23**

(a) Total mercury loading from precipitation on surface water and non-urbanized land surfaces in the Delta and Yolo Bypass was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater by the average rainfall runoff volume during WY2000-2003 (see Section 7.1.4 in Chapter 7 and Section E.2.3 in Appendix E).

(b) The published literature indicates that ratios of methyl to total mercury concentrations in wet deposition typically range from 0.25% to 6%, and that typically less than 1% of total mercury in wet deposition is methylmercury. A methyl to total mercury ratio of 1% was used to estimate the mass of methylmercury deposited to waterways in each subarea.

(c) The Yolo Bypass-North subarea includes areas in the Yolo Bypass north of the legal Delta boundary.

6.2.7 Other Potential Sources

Potential methylmercury sources in the Delta/Yolo Bypass not evaluated by this TMDL may include the following:

- Methylmercury flux from floodplain sediments when floodplains are inundated;
- Agricultural areas in the Yolo Bypass north of the legal Delta boundary;
- Rainwater runoff from agricultural areas throughout the Delta and Yolo Bypass; and
- Runoff from rangeland and other open-space areas not encompassed by urban, wetland, or agricultural areas.

The methylmercury load estimates for methylmercury flux from open water sediments described in Section 6.2.2 do not address floodplain acreage that is not permanently inundated. As illustrated in the Sacramento-San Joaquin Delta Atlas (DWR, 1995), the Delta encompasses a maze of over 1,100 miles of river channels that are almost entirely constrained by local and Federal flood control project levees. Throughout the Delta, there is very little acreage between channel levees not already included in the wetland and open water acreages, with the exception of the Yolo Bypass. The Yolo Bypass is a massive floodplain (about 73,000 acres) on the west side of the lower Sacramento River that receives floodwaters routed from the Sacramento and Feather Rivers by the Fremont and Sacramento Weirs (see Section E.2.2 and Figure E.2 in Appendix E). The Yolo Bypass typically floods in more than half of water years, for an average of two months every other year; complete inundation of the floodplain approximately doubles the wetted area of the Delta and is equivalent to about one-third the area of San Francisco and San

Pablo bays (Sommer *et al*., 2001; Foe *et al.*, 2007). The WY2000-2003 period that encompasses the available methylmercury concentration data for the major Delta inputs and exports was a relatively dry period. However, bypass floodplain inundation may contribute methylmercury loading to the Delta. No floodplain methylmercury loading studies have been completed yet. Preliminary results from ongoing Moss Landing Marine Laboratory and Central Valley Water Board studies indicate that inundated areas in the Yolo Bypass are potentially large sources of methylmercury to the bypass and Delta (Foe, personal communication). Once these and other habitat studies are completed for a range of wet and dry years, staff will re-evaluate methylmercury loading from floodplain areas in the Yolo Bypass.

As noted in Section 6.2.4, the agricultural return flows upon which the return flow methylmercury load estimates are based do not include the Yolo Bypass area north of the legal Delta. In addition, the load estimates address only runoff during the active irrigation season because no methylmercury concentration data is available for stormwater runoff from agricultural areas. Staff recommends that a follow-up study be undertaken to more fully monitor and characterize methylmercury loads from the agricultural areas on Delta Islands and upland areas in the Delta region and, if elevated, determine the primary land uses responsible for methylmercury production. The study should be done in cooperation with agricultural interests in the Delta region.

Similarly, methylmercury concentration data were not available for stormwater runoff from rangeland and other upland areas not encompassed by urban, wetland, water, or agricultural load estimates. Because such upland areas comprise only about 8% of land cover within the Delta and Yolo Bypass, they are not expected to contribute substantially more methylmercury loading than that already present in rainfall, which was estimated for this TMDL. However, such upland areas could account for more of the methylmercury loading to tributary watersheds. Staff recommends that upstream TMDL program studies incorporate analyses of methylmercury in runoff from upland areas.

6.3 Methylmercury Losses

The following were identified as contributing to methylmercury losses from the Delta: water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, biotic uptake and unknown loss term(s). Table 6.15 lists the average methylmercury concentrations and estimated average annual loads associated with the losses for the WY2000-2003 period, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Figure 6.9 shows the aqueous monitoring locations for major methylmercury exports and the approximate locations of recent dredging projects.

Figures and tables cited in Sections 6.3.1 through 6.3.4 are arranged after Section 6.3.4 in the order in which they were mentioned.

Table 6.15: Methylmercury Concentrations and Loads Lost from the Delta for WY2000-2003.

	Average Annual Load (g/yr)	**% All MeHg**	**Average Aqueous Concentration** (ng/l)
Outflow to San Francisco Bay (X2)	1,717	69.7%	0.08
Dredging	341	13.9%	- - -
State Water Project	203	8.2%	0.05
Delta Mendota Canal	201	8.2%	0.06
Photodegradation	*To Be Determined*		
Accumulation in Biota	*Unknown*		
TOTAL EXPORTS:	**2,462 g/yr (2.5 kg/yr)**		

6.3.1 Outflow to San Francisco Bay

Outflow to San Francisco Bay is the primary way that methylmercury is lost from the Delta. Methylmercury in Delta outflow to San Francisco was evaluated by collecting samples at X2. X2 is the location in the Bay-Delta Estuary with 2 parts per thousand (o/oo) bottom salinity. The location of X2 moves as a function of both tidal cycle and freshwater inflow, typically between the Cities of Martinez and Pittsburg, west of the legal Delta boundary. This salinity was chosen because 2 to 3 o/oo salinity is the normal osmotic tolerance of freshwater organisms, and a goal of the CALFED studies was to estimate the methylmercury exposure of these organisms.

Staff from the Central Valley and San Francisco Bay Central Valley Water Boards has agreed to consider Mallard Island as the boundary between the two regions for control of mercury. The site was selected as it is near the legal boundary and has a U.S. Geological Survey flow gauge. Central Valley Water Board staff has begun collecting methylmercury concentration data at Mallard Island and will use this to better estimate advective and dispersive flux of methylmercury from the Central Valley to San Francisco Bay. The data will be collated and a report prepared in the 2008.

Central Valley Water Board staff conducted monthly aqueous methylmercury sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April to September 2003. Figure 6.10 and Table 6.16 summarize the export data. Methylmercury concentrations at X2 averaged 0.075 ng/l and ranged from below detection limits to 0.241 ng/l. Net daily Delta outflow water volumes were obtained from the Dayflow model (Section E.2.4 in Appendix E). Methylmercury concentrations for X2 and net daily Delta outflows were regressed against each other to determine whether flow could be used to predict methylmercury concentration (Appendix F). The regression was significant at $P<0.05$ and accounted for about 20% of the variation in methylmercury concentrations. The regression-based export load was 2,086 g/yr.

An alternate approach is to use average monthly methylmercury concentrations to estimate Delta exports. Concentration data were pooled by month to calculate monthly average concentrations for WY2000-2003 (Table F.1 in Appendix F). Monthly average concentrations were multiplied by monthly average flows for WY2000-2003 to estimate monthly loads and summed to calculate an annual average methylmercury load for WY2000-2003 of 1,717 g/yr. The latter estimate appears similar to the regression-based estimate (2,086 g/yr). Table 6.15 uses an advective export rate of 1,717 g/yr to San Francisco Bay. This accounts for approximately 70% of Delta methylmercury losses. No attempt was made to estimate dispersive loads. It is not known whether dispersive or tidal flows would increase or decrease the net methylmercury load exported to the Bay area.

6.3.2 South of Delta Exports

Water diversions to southern California account for approximately 16% of Delta methylmercury losses (Table 6.15). Methylmercury in Delta Mendota Canal (DMC) and State Water Project (SWP) exports to southern California were evaluated by collecting water samples from the DMC canal off Byron Highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta. Figure 6.9 illustrates the sampling locations.

Central Valley Water Board staff conducted monthly methylmercury sampling at the DMC and SWP from March 2000 to September 2001 (Foe, 2003) and from April 2003 to April 2004. Appendix L provides the methylmercury concentration data collected at the DMC and SWP and Figure 6.10 and Table 6.16 summarize methylmercury concentrations. The volume of water exported by the DMC and SWP was obtained from the Dayflow model (Section E.2.4 in Appendix E). Like at X2, methylmercury concentrations were regressed against daily flow to determine whether the concentrations could be predicted from the flow (Appendix F). Neither regression was significant ($P<0.05$). Therefore, average methylmercury concentrations were used to estimate SWP and DMC export loads of 203 and 201 g/yr, respectively (Table 6.15). Central Valley Water Board staff has collected additional methylmercury data at both pumping sites to better characterize methylmercury loads as part of a larger CALFED study. The study will be completed and a report published in 2008.

6.3.3 Export via Dredging

Sediment is dredged at various locations in the Delta to maintain ship channels and marinas. No data have been gathered on methylmercury levels in dredge material removed from the Delta. To determine whether dredging activities could result in notable methylmercury loss from the Delta, a preliminary load estimate was developed using available dredge volume and total mercury information and surficial sediment methylmercury concentration data. Methylmercury removed by dredge activities could account for almost 14% of the identified methylmercury exports from the Delta (Table 6.15).

Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return flow. Table 6.17 provides information for recent dredge projects within the

Delta and Figure 6.9 shows their approximate locations. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,400 cubic yards of sediment are dredged annually on average, with 199,000 cubic yards from the Sacramento Deep Water Ship Channel and 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects at marinas remove sediment at various frequencies for a combined total of about 64,400 cubic yards per year. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.41 mg/kg (dry weight). The annual mass of mercury removed from the Delta through dredging projects is approximately 57 kg/year. Section 7.2.3 provides a description of the methods used to estimate the annual mass of total mercury removed by dredging and the uncertainty in the estimate. None of the dredging projects analyzed sediment samples for methylmercury. Heim and others (2003) evaluated surficial sediment MeHg:TotHg at several locations in the Sacramento and Stockton Deep Water Channels (Table 6.18), where nearly 90% of all dredged materials from the Delta are removed. The average MeHg:TotHg of 0.006 was used to estimate the mass of methylmercury removed by dredging projects:

Equation 6.3:

$$\text{MeHg Mass} = \text{Total mercury mass} * \text{MeHg:TotHg}$$
$$341\ \text{g/yr} = 57\ \text{kg/year} * 1000\ (\text{g/kg}) * 0.006$$

Use of surficial sediment MeHg:TotHg to estimate methylmercury mass removed by dredging assumes that MeHg:TotHg is consistent throughout all depths of sediment in the dredged areas, which may overestimate the mass removed if methylmercury levels actually decrease with depth. In addition, methylmercury production may increase after dredging activities if the newly exposed sediment has higher total mercury concentrations. Central Valley Water Board staff recommends that dredgers quantify the amount of methylmercury removed and that the mercury concentration of fine grain material in newly exposed sediment be assayed (see Chapter 4 in the draft Basin Plan Amendment staff report).

6.3.4 Other Potential Loss Pathways

Accumulation by biota and photodegradation throughout the Delta have not yet been evaluated. The amount of methylmercury accumulating in aquatic biota is not known. However, studies could be undertaken to ascertain the rate of transfer from the abiotic to the biotic component of the food web. Preliminary study results for the Sacramento River near Rio Vista indicate surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' preliminary results are similar to photodegradation rates observed in Florida and Canada. Methylmercury photodegradation rates in a boreal forest lake in northwestern Ontario, Canada, ranged between -3 and 27% per day, with the highest rates at the lake surface (Sellers and Kelly, 2001). In the Everglades, Krabbenhoft and others (1999) observed methylmercury degradation rates ranging from 2 to 15% per day. Krabbenhoft and others (1999 and 2002) also found that the majority of photodegradation occurred in the top half meter of water; however, they also found that the rate of degradation was largely dependent on the concentration of dissolved organic carbon. The large surface to depth ratio of the Delta, coupled with its relatively long residence time, may result in significant loss of methylmercury by photodegradation. Byington and others' extrapolation of their preliminary study results suggests a loss of about 4 g/day over the entire Delta. Photodemethylation experiments are continuing as part of an ongoing CALFED-funded project (Proposal ERP-02-C06-B).

Table 6.16: Methylmercury Concentrations for the Delta's Major Exports

Site	# of Samples	Min. MeHg Conc. (ng/l) [(a)]	Ave. MeHg Conc. (ng/l)	Annual Ave. Conc. (ng/l) [(b)]	Median MeHg Conc. (ng/l)	Max. MeHg Conc. (ng/l)
Delta Mendota Canal	21	ND	0.062	0.064	0.061	0.171
State Water Project	20	ND	0.051	0.054	0.049	0.144
Outflow to San Francisco Bay (X2)	22	ND	0.075	0.083	0.070	0.241

(a) ND: below method detection limit.

(b) Sampling of these exports took place between March 2000 and September 2003. Methylmercury concentration data were pooled by month to estimate monthly average methylmercury concentrations and loads (Table F.1 in Appendix F); the monthly average loads were summed to estimate annual average methylmercury loads for water years 2000-2003. The monthly average concentrations were averaged to estimate annual average concentrations, which were included in Table 6.15.

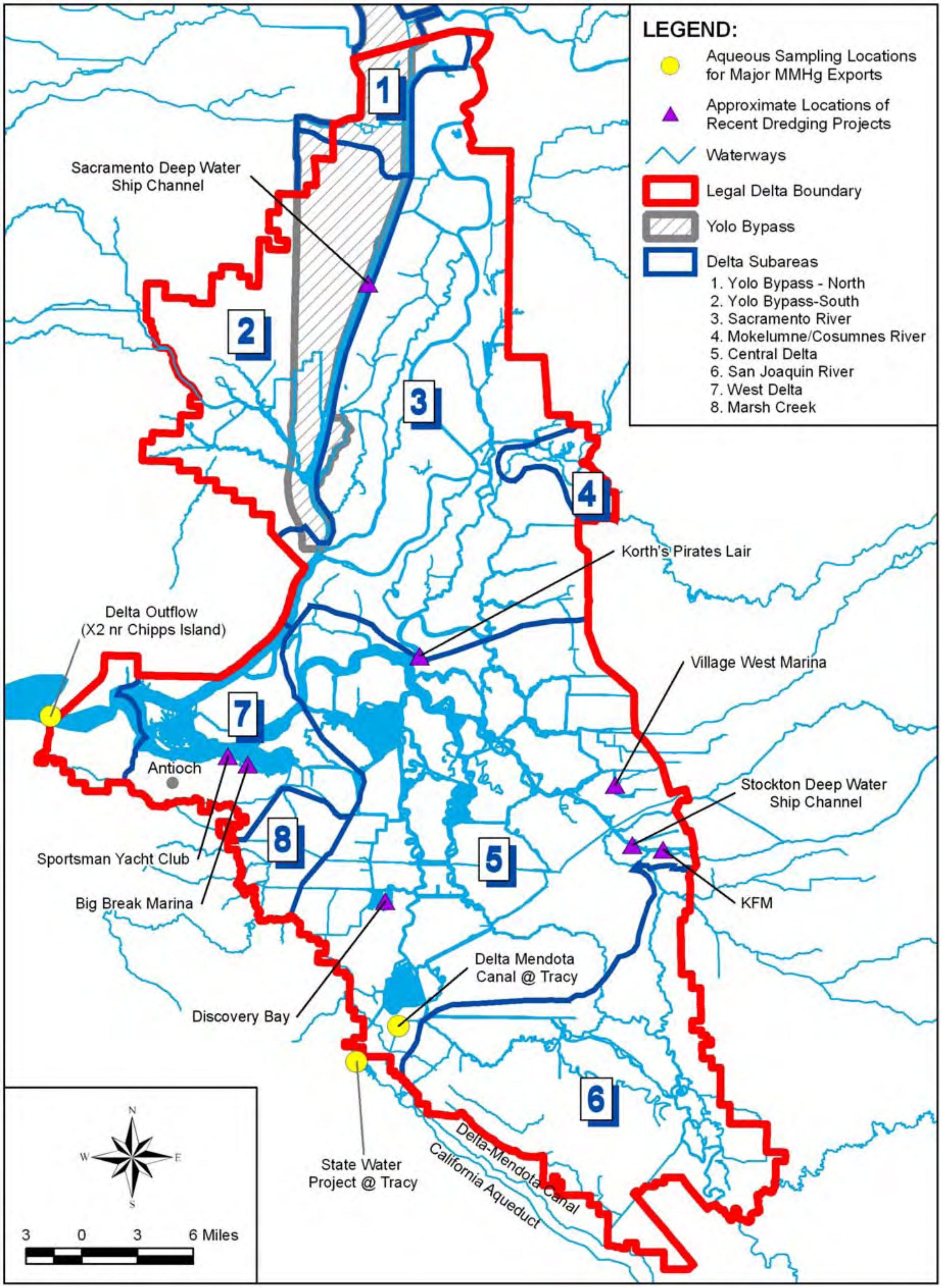

Figure 6.9: Aqueous Monitoring Locations for Major Methylmercury Exports and Approximate Locations of Recent Dredging Projects.

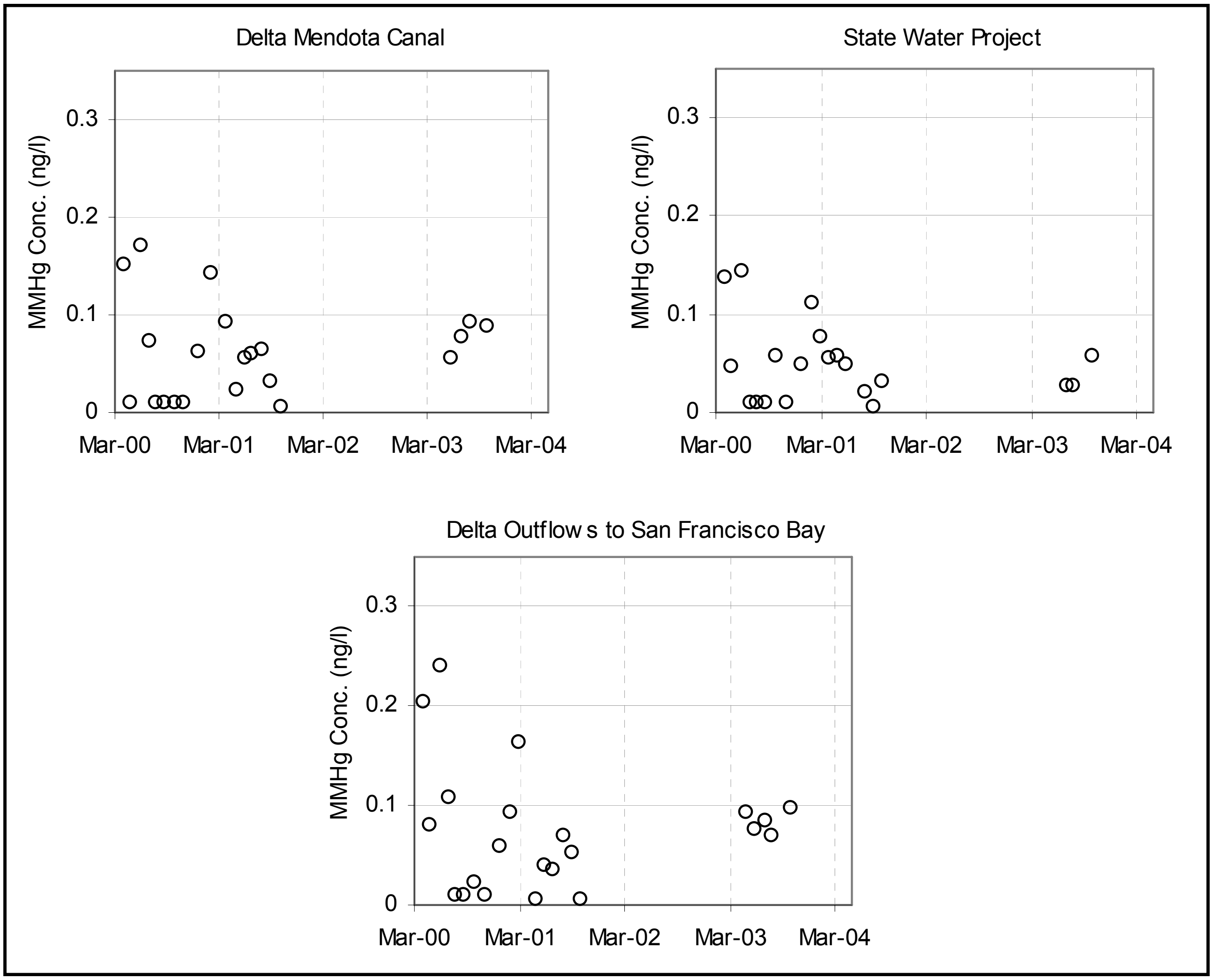

Figure 6.10: Available Methylmercury Concentration Data for the Delta's Major Exports

Table 6.17: Recent Dredge Projects within the Delta.

Delta Dredging Project	Project Location	Volume of Dredge Material (cubic yards)	Dredge Frequency	Disposal Location (upland, Delta island, wetland areas, etc.)	Mean Sediment Mercury Conc. (mg/kg, dry wt) [a]	# of Samples	Standard Dev.	T Value (p=0.975, conf 95%, df =n-1)	Total Weight of Mercury Removed (kg)	Annual Weight of Mercury Removed [a] (kg)	Annual Weight of Sediment Removed (Mkg, dry wt)	Annual Volume of Water Removed (acre-feet)	Does Effluent Return to a Receiving Water?	Average Effluent Hg Conc. (μg/l)
Sac. River Deep Water Ship Channel [b]	Sacramento River	199,000	Annually	Delta Island/ upland	0.37 ±3.93	2	0.4377	12.71	42	42 ±446 (n)	110.5	89.6	No	0.05 to 0.1
Stockton Deep Water Channel [c]	San Joaquin River	270,000	Annually	Delta Islands	0.083 ±0.023	28	0.0594	2.052	13	13 ±3.5	150.0	121.5	No	0.05 to 0.13
Village West Marina [d]	14-Mile Slough	70,000	Every 10 years	Delta Islands	0.043 ±0.014	3	0.0058	4.303	1.7	0.2 ±0.057	3.9	3.2	Yes [l]	0.05
KFM [e]	San Joaquin River	3,000	One time	Upland	*Unknown*						1.7	1.4	No	0.05
Korths Pirates Lair [f]	Mokelumne River	15,000	Every 5 years	Upland	0.15 ±0.11	2	0.0120	12.71	1.3	0.25 ±0.18	1.7	1.4	No	0.05
Big Break Marina [g]	San Joaquin River	12,000	Every 5 years	Upland	0.41 ±0.24	6	0.2318	2.571	2.8	0.55 ±0.33	1.3	1.1	No	0.25
Sportsman Yacht Club [h]	San Joaquin River	10,000	Every 5 years	Upland	0.12 ±0.014	3	0.0058	4.303	0.70	0.14 ±0.016	1.1	0.9	No	0.05
Discovery Bay [i]	Delta	50,000 [j]	Annually	Upland	0.027 ±0.018	7	0.0195	2.447	0.78	0.78 ±0.51	27.8	22.5	Yes [k, l]	0.05
Annual Averages [m]		**533,400 cubic yards**								**57 ±451 kg** [n]	**349 Mkg**	**241 a-ft**		

(a) The uncertainty of the mercury load values was estimated by calculating the 95% confidence interval for the mean of the concentration data for each project.
(b) U.S. Army Corps of Engineers, 2002 NOI (Notice of Intent) Sacramento DWSC.
(c) U.S. Army Corps of Engineers, 2000-2003 NOI Stockton DWSC.
(d) DCC Engineering Co, Inc., Village West Dredge Material Test, September 5, 2000.
(e) KFM, 401 Water Quality Certification.
(f) Anderson Engineers, 2003 Sediment Sampling and Analysis Plan for Korths Pirates Lair.
(g) Subsurface Consultants, Inc., Environmental Site Assessment 2001 & Aquifer Sciences, Inc., Pre-Dredge Sampling and Analysis Plan July 29, 2003.
(h) Padre Associates, Inc., Laboratory Analytical Results of Proposed Dredge Material and Associated Waste Classification May 23, 2003.
(i) Kennetic Laboratories/ToxScan, Inc., Sediment Properties and Chemistry April 2002, Discovery Bay, 2003 Final Water Quality Monitoring Report, WDR Order No. R5-2003-0027.
(j) Discovery Bay assumptions: The initial dredge project was 153,000 cubic yards, and 50,000 cubic yards/year thereafter. Therefore, assume 50,000 cy/year.
(k) WDR Order N. R5-2003-0027 indicates effluent returned to Discovery Bay averaged 3 mgd for several days to several weeks; staff assumed discharge period is 14 days/year.
(l) Two dredging projects, Village West Marina and Discovery Bay, had effluent that returned to Delta waters. The volume of effluent returned to receiving waters by the Discovery Bay project was approximately 42 million gal/year. The volume of effluent returned by the Village West Marina project is unknown. Staff estimated that the annual weight of mercury returned by the Discovery Bay dredge effluent was 0.008 kg, assuming that all water was returned.
(m) Annual averages do not include KFM, a one-time project.
(n) The uncertainty associated with the amount of mercury removed by dredging in the Sacramento Deep Water Ship Channel is particularly substantial (±446 kg), as a consequence of its calculation being based on only two sample results (0.68 and 0.061 mg/kg mercury) that have a tenfold range.

Table 6.18: MeHg:TotHg in Deep Water Ship Channel Surficial Sediments

	MeHg Conc. (ng/g)	**TotHg Conc.** (ng/g)	**MeHg:TotHg Ratio**
Sacramento Deep Water Ship Channel [(a)]			
Sacramento River DWSC	0.49	194.70	0.0025
Stockton Deep Water Channel [(a)]			
Little Connection Slough	0.20	82.51	0.0024
Headreach Cutoff	1.86	89.46	0.0208
Port of Stockton Turnabout #1	0.32	193.78	0.0017
Port of Stockton Turnabout #2	0.32	130.30	0.0025
		AVERAGE RATIO:	**0.006**

(a) Source: Heim *et al.*, 2003. Latitude/longitude coordinates provided with the above samples indicated that these were collected within the dredged deep water ship channels.

6.4 Delta Methylmercury Mass Budget & East-West Concentration Gradient

Figure 6.11 provides an idealized illustration of the Delta's average daily methylmercury imports and exports based on the annual loads presented in Tables 6.2 and 6.15. *In situ* sediment production and tributary water bodies account for about 35 and 58%, respectively, of methylmercury inputs to the Delta. Agricultural return flow and NPDES-permitted wastewater treatment plants are responsible for about 6% of the load while runoff from urban areas within the Delta/Yolo Bypass contributes about 0.4%.

The difference between the sum of known inputs and exports is a measure of the uncertainty of the loading estimates and of the importance of other unknown processes at work in the Delta. As noted in Section 6.2, the sum of WY2000-2003 water imports and exports balances within approximately 5%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. Average annual methylmercury inputs and exports were approximately 14.3 g/day (5.2 kg/yr) and 6.7 g/day (2.5 kg/yr), respectively (Tables 6.2 and 6.15 and Figure 6.11). Exports are only about 50% of inputs, suggesting that the Delta acts as a net sink for methylmercury.

A special study was conducted in the summer of 2001 to ascertain the location where much of the decrease in methylmercury occurred (Foe, 2003). Three transects were run down the Sacramento River and out toward San Francisco Bay, the water path from the main tributary source (Sacramento River) to the main export of methylmercury (Suisun Bay). The largest decrease in concentration consistently occurred in the vicinity or immediately downstream of Rio Vista (Figure 6.12). The drop in concentration was between 30 and 60%. The processes contributing to the loss are not known but are the subject of ongoing CALFED research (ERP-02-C06-B, Tasks 5A and 5B). For example, as described in the previous section, preliminary photodegradation study results for the Sacramento River near Rio Vista indicate relative surface water photodegradation rates of about 30% of the dissolved methylmercury per day at the top half meter of water (Byington *et al.*, 2005). Byington and others' extrapolation of their preliminary study results over all Delta waters suggests a loss of about 4 g/day, which could account for more than 50% of the 7.6 g/day unknown loss rate illustrated in Figure 6.11.

Additional research is ongoing or proposed in Chapter 4 of the draft BPA report (Implementation) that includes monitoring to better characterize source concentrations and loads. Improvements made to the load estimates could affect the methylmercury load allocations calculated in Chapter 8.

Key points for the methylmercury source analysis are listed after Figures 6.11 and 6.12.

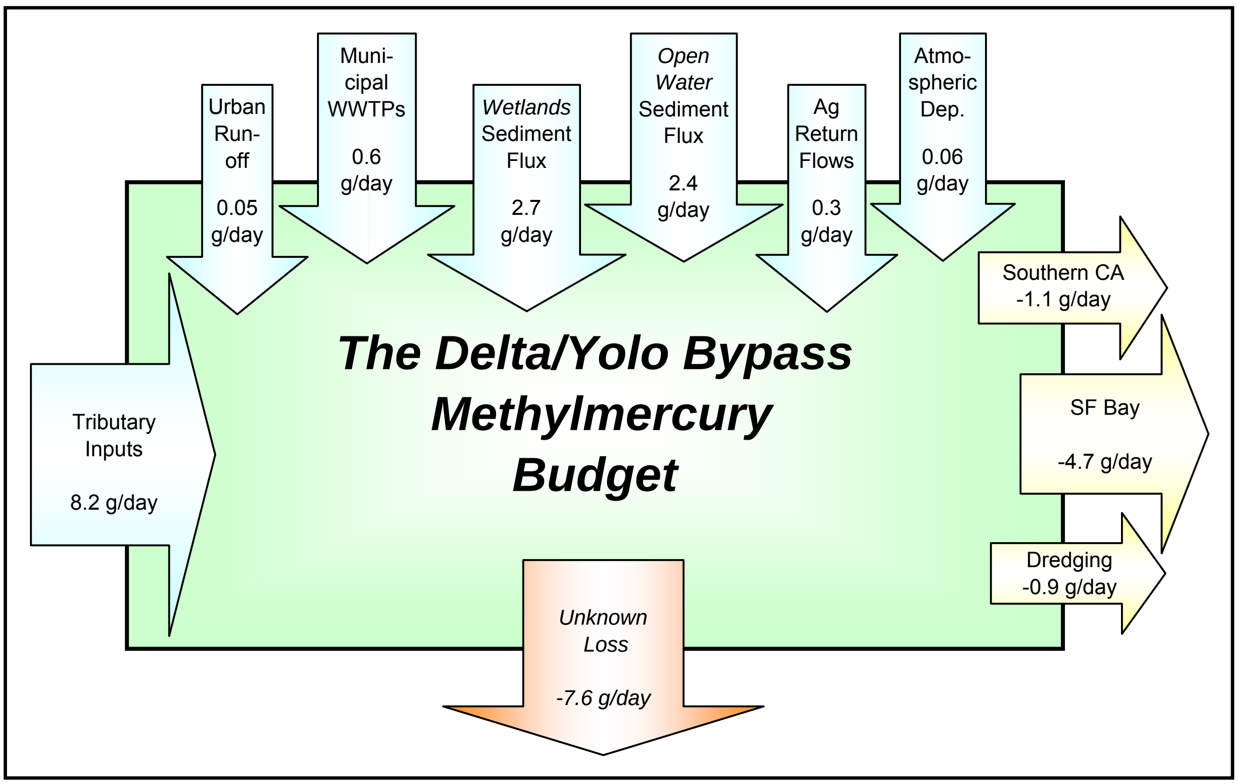

Figure 6.11: Average Daily Delta/Yolo Bypass Methylmercury Inputs and Exports. The rate of unidentified loss processes was determined by subtracting the sum of the inputs from the sum of the exports.

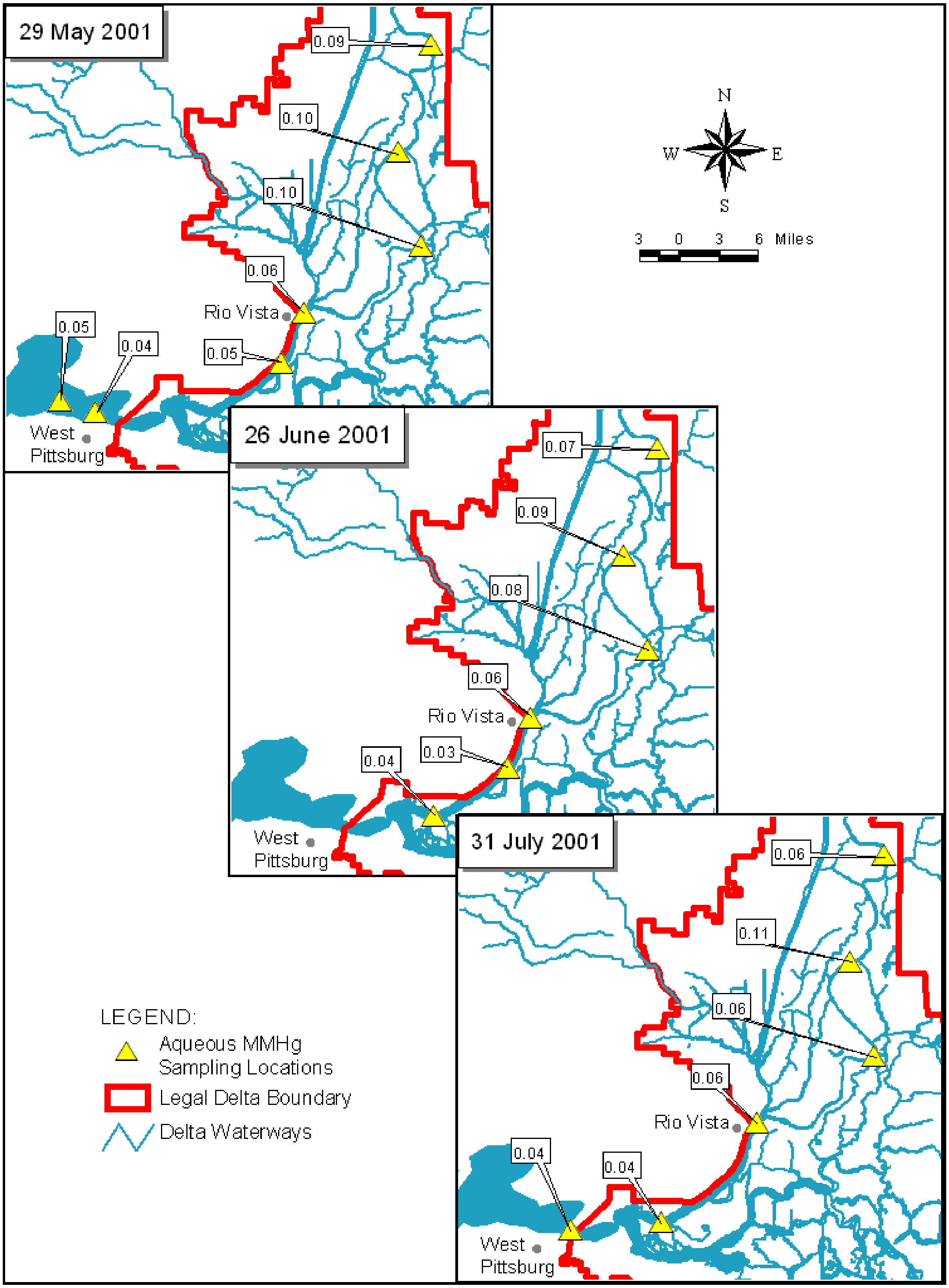

Figure 6.12: Water Sampling Transects down the Sacramento River to Ascertain Location of Methylmercury Concentration Decrease. Westernmost sampling stations changed with each transect depending on the locations of 1 o/oo through 5 o/oo bottom salinities, which move as a function of tidal cycle and freshwater inflow. (Data source: Foe, 2003.)

Key Points

- Sources of methylmercury in the Delta/Yolo Bypass include tributary inflows from upstream watersheds and within-Delta/Yolo Bypass sources such as methylmercury flux from sediment in wetland and open water habitats, municipal and industrial wastewater, agricultural drainage, and urban runoff. Approximately 58% of identified methylmercury loading to the Delta comes from tributary inputs while within-Delta sources account for approximately 42% of the load.
- Losses include water exports to southern California, outflow to San Francisco Bay, removal of dredged sediments, photodegradation, uptake by biota, and unknown loss term(s). Outflow to San Francisco Bay accounted for about 70% of identified methylmercury exports.
- The sum of WY2000-2003 water imports and exports balances within approximately 5%, and the sum of WY2000-2003 water imports and exports balances within approximately 1%, indicating that all the major water inputs and exports have been identified. In contrast, the methylmercury budget does not balance. A comparison of the sum of identified inputs (5.2 kg/yr) and exports (2.5 kg/yr) indicates that there is an unknown loss term of approximately 50%. Preliminary study results suggest that photodegradation may explain more than 50% of that loss term.

7 SOURCE ASSESSMENT – TOTAL MERCURY & SUSPENDED SEDIMENT

Sources and losses of total mercury and suspended sediment are described in this chapter. The Delta mercury TMDL program addresses total mercury in addition to methylmercury because:

- Methylmercury production has been found to be a function of the total mercury content of the sediment (Chapter 3), and decreasing total mercury loads may be an option for controlling methylmercury;
- The mercury control program for the Delta must maintain compliance with the USEPA's CTR criterion of 50 ng/l for total recoverable mercury for freshwater sources of drinking water developed for human protection; and
- The mercury TMDL for San Francisco Bay assigns a total mercury load reduction to the Central Valley watershed to protect human and wildlife health in the San Francisco Bay (Johnson and Looker, 2004). The San Francisco Bay mercury control program approved by the State Water Board requires a reduction of 110 kg/yr of mercury from all sources entering the Delta or in water moving past Mallard Island. Meeting the San Francisco Bay goal will require a quantitative understanding of mercury and sediment loads entering and leaving the Delta.

Sections 7.1 and 7.2 describe mercury and suspended sediment concentrations (measured as total suspended solids, or TSS) for Delta sources and sinks and identify major data gaps and uncertainties. Input and loss loads were calculated for WY2000-2003, a relatively dry period corresponding to the available methylmercury data. In addition, the WY1984-2003 period was evaluated to determine mass balances for a more typical hydrologic period. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin since accurate water records began to be collected (about 100 years). An assessment of mass balances during a typical distribution of wet and dry water years is critical because transport of sediment and mercury is a function of water velocity and volume.

Section 7.3 presents the total mercury and suspended sediment mass budgets based on the input and export loads described in Sections 7.1 and 7.2. Section 7.4.1 reviews the mercury-to-TSS ratio (TotHg:TSS) for each input and export site to identify areas that may be the focus of future remediation efforts to reduce total mercury loading. Finally, Section 7.4.2 evaluates compliance with the CTR.

7.1 Total Mercury and Suspended Sediment Sources

The following were identified as sources of total mercury and suspended sediment to the Delta: tributary inflows from upstream watersheds, municipal wastewater, atmospheric deposition, and urban runoff. Table 7.1 lists the estimated loads associated with each source for WY2000-2003 and WY1984-2003.

Table 7.1: Average Annual Total Mercury and TSS Source Loads for WY2000-2003 and WY1984-2003.

	WY2000-2003				WY1984-2003			
	TotHg		TSS		TotHg		TSS	
	kg/yr ± 95% CI	% of All Inputs	Mkg/yr ± 95% CI	% of All Inputs	kg/yr ± 95% CI	% of All Inputs	Mkg/yr ± 95% CI	% of All Inputs
Tributary Inputs [a, b]								
Sacramento River	146 ±1	66%	689 ±7	64%	183 ±1	45%	865 ±7	40%
Prospect Slough	37 ±1	17%	197 ±5	18%	169 ±5	42%	1,014 ±31	47%
San Joaquin River	18 ±2	8.2%	138 ±23	13%	29 ±4	7.2%	223 ±37	10%
Calaveras River	3.8 ±2	1.7%	15 ±21	1.4%	4.1 ±2	1.0%	16 ±23	0.7%
Mokelumne-Cosumnes Rivers	2.8 ±0.6	1.3%	7.7 ±2	0.7%	4.6 ±1	1.1%	12 ±3	0.6%
Ulatis Creek	2.1 ±2	1.0%	16 ±19	1.5%	2.2 ±2	0.5%	17 ±19	0.8%
French Camp Slough	1.6 ±3	0.7%	2.3 ±2	0.2%	1.7 ±3	0.4%	2.4 ±2	0.1%
Morrison Creek	0.79 ±0.2	0.4%	4.3 ±2	0.4%	0.83 ±0.2	0.2%	4.5 ±2	0.2%
Marsh Creek	0.54 ±0.01	0.3%	1.1 ±11	0.1%	0.54 ±0.01	0.1%	1.1 ±11	0.1%
Bear/Mosher Creeks	0.29 ±0.2	0.1%	2.4 ±5	0.2%	0.30 ±0.2	0.1%	2.4 ±5	0.1%
Sum of Tributary Sources:	**213 ±4**	**97%**	**1,073 ±28**	**99%**	**395 ±7**	**98%**	**2,157 ±51**	**>99%**
Inputs within the Delta/Yolo Bypass								
Wastewater	2.5	1.1%			2.5	0.6%		
Urban	2.3	1.1%	7.5	0.7%	2.4	0.6%	7.8	0.4%
Atmospheric (Indirect)	1.5	0.7%			1.5	0.4%		
Atmospheric (Direct)	0.81	0.4%			0.84	0.2%		
Sum of Within-Delta Sources:	**7.1**	**3%**	**7.5**	**1%**	**7.2**	**2%**	**7.8**	**<1%**
TOTAL INPUTS:	**220 ±4**		**1,080 ±28**		**403 ±7**		**2,165 ±51**	

(a) Confidence intervals (CI) were calculated for the average annual loads for inputs with daily flow data. See Appendix I for the calculation methods.

(b) Total mercury and TSS concentrations are not available for several small drainages to the Delta, including the following areas shown on Figure 6.1: Dixon, Upper Lindsay/Cache Slough, Manteca-Escalon, Bethany Reservoir, Antioch, and Montezuma Hills areas.

7.1.1 Tributary Inputs

During WY2000-2003, tributaries to the Delta contributed approximately 97% of the mercury and 99% of the suspended sediment (Table 7.1). The Sacramento Basin alone (Sacramento River at Freeport + Yolo Bypass) contributed more than 80% of all mercury and TSS loads. The load estimates in Table 7.1 are based on the water volumes described in Section 6.1 and Appendix E and concentration data collected by several agencies provided in Appendix L.

Central Valley Water Board staff began evaluating mercury loads from the Sacramento River watershed and Yolo Bypass in 1994 (Foe and Croyle, 1998). From March 2000 to September 2001, staff conducted monthly sampling at the Delta's four major tributary input sites (Foe, 2003): Sacramento River; San Joaquin River; Mokelumne River (downstream of the Mokelumne/Cosumnes Rivers confluence); and Prospect Slough at Toe Drain in the Yolo Bypass. In addition, other programs conducted periodic aqueous sampling between 1993 and 2003 on the Sacramento River (SRWP, 2004; CMP, 2004; Stephenson *et al.*, 2002). Central Valley Water Board staff resumed sampling in April 2003. Figure 6.2 shows the tributary monitoring locations. Table 7.2 and Figures I.1 through I.6 in Appendix I summarize the available mercury and TSS data.

Sections 7.1.1.1 through 7.1.1.3 describe the methods used to estimate the loads for the Delta's tributary watersheds and identify uncertainties. Because the Sacramento Basin is the primary source of mercury to the Delta, Section 7.1.1.3 provides an analysis of loading from major upstream Sacramento River tributaries. This information may be valuable for designing follow-up studies to determine where to implement mercury control programs.

7.1.1.1 Sacramento Basin Inputs to the Delta

Sacramento Basin mercury and TSS discharges to the Delta were determined for the Sacramento River at Freeport and the Yolo Bypass at Prospect Slough. Mercury and TSS concentrations for the Sacramento River at Freeport were regressed against Freeport flow to determine if a relationship might exist. Both regressions were statistically significant ($P< 0.01$) indicating that it is possible to predict Sacramento River mercury and TSS concentrations from flow. The mercury/flow and TSS/flow equations were used to predict average annual loads[37,38]. The methods used to calculate the 95% confidence intervals are described in Appendix I. The average annual load for the Sacramento River was 146 kg mercury and 689 Mkg TSS for WY2000-2003, and 183 kg mercury and 865 Mkg TSS for WY1984-2003 (Table 7.1).

Prospect Slough is a major channel draining the Yolo Bypass. Total mercury and TSS samples were collected in Prospect Slough during outgoing tides. Mercury and TSS concentrations observed on dates with net outflow were regressed against daily outflows at Lisbon Weir lagged by one day[39] to determine if statistically significant correlations might exist (Section E.2.2 in Appendix E and Figure I.1 in Appendix I). Extremely high mercury and TSS concentrations were measured on 10 and 11 January 1995 (Figure I.1). These values were not included in the regressions because, as described in Section E.2.2, the hydrologic conditions that caused them appear to have occurred only once during the WY1984-2003 study period. The TotHg/flow and TSS/flow regressions for Prospect Slough were significant ($P< 0.01$, Figure I.7a and I.7b), indicating that the concentrations of both constituents could be predicted from flow. The

---

[37] For all tributaries with statistically significant TotHg/flow or TSS/flow relationships, the predicted concentrations were multiplied by daily flow volumes to estimate daily loads. The estimated daily loads were summed and then divided by the number of years in the study period to estimate the average annual loads for WY2000-2003. If a flow record had dates with missing values, the data were normalized to estimate annual loads. For example, a 20-year record would be normalized by dividing 7305 (the number of days in the 20-year period) by the number of days with a recorded value in the flow record and then multiplying the resulting quotient by the calculated sum of loads; the result was then divided by 20 to obtain the average annual load.

[38] The Delta area that drains to the 13-mile reach of the Sacramento River between Freeport (near river mile 46) and the I Street Bridge (the northernmost legal Delta boundary, near river mile 59) is predominantly urban and is encompassed by the urban load estimate described in Section 5.2.5. No attempt was made to subtract this area from the Sacramento River watershed load estimate. Therefore, the Sacramento River load noted in Table 7.1 incorporates a small portion of the within-Delta urban runoff loading.

[39] The estimated daily flows from Lisbon Weir on Toe Drain were lagged one day to address the approximate residence time of water along the ~15 miles between Lisbon Weir and Prospect Slough. During drier years, there may be little-to-no net outflow from the Yolo Bypass's Toe Drain downstream of Lisbon Weir between April and November. (See Appendix E for a description of Yolo Bypass hydrology.) Therefore, although sampling of Prospect Slough took place during outgoing tides with the intent of sampling outflows from the Yolo Bypass, during the summer months this sampling most likely represents waters tidally-pumped northward from Cache Slough, rather than outflows from the Yolo Bypass north of Lisbon Weir.

regressions were used to estimate annual average loads of 37 kg mercury and 197 Mkg TSS for WY2000-2003 and 169 kg mercury and 1,014 Mkg TSS for WY1984-2003 (Table 7.1). The five-fold increase in loads during the wetter WY1984-2003 years illustrates the importance of basing load calculations on the long-term average hydrology of the basin.

All other studies that have evaluated mercury and sediment loads from the Sacramento Basin are summarized in Table 7.3. The Sacramento watershed is the major source of water, mercury, and sediment to the Delta. The results confirm that export from the watershed is strongly a function of water year type. The lowest mercury export rate occurred during the driest study period (94.8 kg/yr; Foe 2003), while the highest (801 kg/yr; Foe and Croyle, 1998) was during a very wet period. Most annual loading rates fall between 200 and 500 kg of mercury per year.

The WY1984-2003 mercury-loading rate of 349±7 kg/yr is midway between these values. The most comparable study is likely that of LWA (2002), which estimated an export rate of 306 kg/yr of mercury for another relatively similar 20-year hydrologic period. The difference between the two 20-year periods, while statistically significant, is only about 10%. Interestingly, the Sacramento River is the primary source of mercury to the Delta during dry years, but exports from the Yolo Bypass increase and become comparable to Sacramento River loads during wet periods.

Sediment transport is also strongly a function of water year type (Table 7.3). The smallest export rate occurred during the driest period studied (568 Mkg/yr, Foe, 2003), while the highest rate happened during a wet year (3,900 Mkg/yr, Foe and Croyle, 1998). The WY1984-2003 sediment export rate of 1,894 ±32 Mkg/yr is among the higher reported. The importance of the Yolo Bypass, like for mercury, is strongly a function of flow. The Bypass only exports a small amount of sediment during dry periods, but loads increase and equal or exceed those of the Sacramento River during wet periods.

The sediment yield of the Sacramento Basin is reported to have declined by about 50% since 1957 (Wright and Schoellhamer, 2004). Primary causes are believed to be the reduced supply of erodible material since cessation of hydraulic mining and increased trapping of sediment in reservoirs. Therefore, future Sacramento Basin mercury and sediment export rates may be different than those computed with the present rating curves.

Space intentionally left blank.

Table 7.2: Total Mercury and TSS Concentrations for Tributary Inputs

Site [a]	# of Samples	Sampling Begin Date	Sampling End Date	Min. Conc.	Ave. Conc.	Median Conc.	Max. Conc.
TOTAL MERCURY CONCENTRATIONS (ng/l)							
Bear/Mosher Creeks [b]	4	3/15/03	2/26/04	3.55	8.08	8.70	11.36
Calaveras River @ RR u/s West Lane [b]	4	3/15/03	2/26/04	13.23	20.53	21.34	26.22
French Camp Slough near Airport Way	5 [4]	7/11/00	2/26/04	1.73 [3.32]	16.75 [20.5]	4.71 [11.63]	55.42 [55.42]
Marsh Creek @ Hwy 4	19 [3]	11/05/01	2/02/04	0.93	7.34	4.36	30.18
Mokelumne River @ I-5	21	3/28/00	9/30/03	0.26	5.34	5.19	12.28
Morrison Creek [c]	47 [15]	4/09/97	1/28/02	1.62 [3.9]	7.96 [10.46]	7.23 [9.12]	19.75 [19.75]
Prospect Slough (Yolo Bypass) [d]	28 [26]	1/10/95	9/30/03	10.58	73.22 (30.80)	26.70 (25.73)	695.6 (92.2)
Sacramento River @ Freeport	155	2/15/94	11/06/02	1.20	8.28	6.31	36.19
San Joaquin River @ Vernalis	34	10/29/93	2/26/04	3.12	7.99	7.33	21.73
Ulatis Creek near Main Prairie Rd	6 [4]	1/28/02	2/26/04	1.34 [24.21]	36.06 [53.24]	28.68 [52.51]	83.74 [83.74]
TSS CONCENTRATIONS (mg/l)							
Bear/Mosher Creeks [b]	4	3/15/03	2/26/04	15.8	65.8	24.1	199.1
Calaveras River @ RR u/s West Lane [b]	4	3/15/03	2/26/04	32.4	82.7	55.4	187.5
French Camp Slough near Airport Way	5 [4]	1/28/02	2/26/04	12.0 [16.7]	26.0 [29.5]	26.4 [27.5]	46.5 [46.5]
Marsh Creek @ Hwy 4	7 [2]	3/15/03	2/02/04	17.9 [36.9]	69.1 [155.0]	36.9 [155.0]	273.2 [273.2]
Mokelumne River @ I-5	23	3/28/00	9/30/03	5.8	14.5	12.0	31.0
Morrison Creek [c]	44 [15]	4/09/97	1/28/02	6.0 [7.0]	39.9 [57.0]	27.0 [40.5]	140 [140]
Prospect Slough (Yolo Bypass) [d]	26 [24]	1/10/95	9/30/03	36.6	298.4 [166.8]	143.2 [139.9]	2300.7 [512.7]
Sacramento River @ Freeport	187	12/15/92	1/20/04	<0.5	38.0	26.0	368.0
San Joaquin River @ Vernalis	29	3/28/00	2/26/04	20.0	61.1	56.0	170.8
Ulatis Creek near Main Prairie Rd.	6 [4]	1/28/02	2/26/04	2.5 [140.2]	276.5 [411.6]	217.8 [338.4]	829.6 [829.6]

(a) Flow gage data were not available for most of the small tributary outflows to the Delta. Therefore, wet weather concentration data (noted in brackets) and estimated wet weather runoff (Section E.2.3 in Appendix E) were used to develop load estimates.

(b) Only wet weather events were sampled on the Calaveras River and Bear and Mosher Creeks in Stockton. The one wet weather Mosher Creek sample result was combined with the Bear Creek data to estimate loads for both creeks (Appendix I).

(c) Concentration data collected at multiple sites on lower Morrison Creek were compiled to develop load estimates (Appendix I).

(d) Sampling took place at Prospect Slough (export location of the Yolo Bypass) both when there were net outflows from tributaries to the Yolo Bypass and when there was no net outflow (i.e., the slough's water was dominated by tidal waters from the south). The regression analysis focuses only on the conditions when there was net outflow from the Yolo Bypass. The above values do not include data collected when there was no net outflow. The values in parentheses are from calculations without the two very high values shown in Figure I.1. The regression is between total mercury concentrations observed at Prospect Slough (not including the two very high values shown in Figure I.1) and total export flows for the previous day estimated for Lisbon Weir, approximately 15 miles north of the Prospect Slough sampling station. The previous day's flow values were used to address the approximate residence time of the water as it travels through the Yolo Bypass to the export location where samples were collected.

Table 7.3: Comparison of Load Estimates for Sacramento Basin Discharges to the Delta

Study	Sampling Location	Period	Average Sacramento Valley Water Year Hydrologic Index [(a)]	Average Annual TotHg Load [± 95 CI] (kg)	Average Annual TSS Load [95% CI] (Mkg)
Sacramento River					
Delta Mercury TMDL [(b)]	Freeport	WY2000-2003	7.3	146 ± 1	689 ± 7
		WY1984-2003	7.8	183 ± 1	865 ± 7
Foe and Croyle (1998)	Greene's Landing	May 1994- April 1995	12.9	426	1,400
Foe (2003)	Greene's Landing	WY2001 [(c)]	5.8	91	526
LWA (2002)	Freeport	WY1980-1999	8.5	189 ± 2	na
Wright & Schoellhamer (2005)	Freeport	WY1999-2002	7.7	na	1,100 ± 170
Yolo Bypass					
Delta Mercury TMDL	Prospect Slough	WY2000-2003	7.3	37 ± 1	197 ± 5
		WY1984-2003	7.8	169 ± 5	1,014 ± 31
Foe and Croyle (1998)	Prospect Slough	May 1994- April 1995	12.9	375	2,500
Foe (2003)	Prospect Slough	WY2001 [(c)]	5.8	3.8	42
LWA (2002)	Woodland	WY1980-1999	8.5	118 ± 17	na
Wright & Schoellhamer (2005)	Woodland	WY1999-2002	7.7	na	310 ± 130
Sacramento Basin Total (Sacramento River + Yolo Bypass)					
Delta Mercury TMDL		WY2000-2003	7.3	183 ± 1	886 ± 9
		WY1984-2003	7.8	352 ± 5	1879 ±31
Foe and Croyle (1998)		May 1994- April 1995	12.9	801	3,900
Foe (2003)		WY2001 [(c)]	5.8	94.8	568
LWA (2002)		WY1980-1999	8.5	306	na
Wright & Schoellhamer (2005)		WY1999-2002	7.7	na	1,410 ± 300
Domagalski (2001) [(d)] 3 winter seasons, 20 December to 20 March		WY1997	10.8	487	na
		WY1998	13.3	506	na
		WY1999	9.8	169	na

(a) Source: DWR, 2006 (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). DWR calculated a hydrologic index for the Sacramento Valley (Section E.1 in Appendix E). "Normal" hydrologic conditions for the Sacramento Valley are represented by an index value of 7.8, "wet" ≥9.2, "dry" 5.4 to 6.5, and "critical dry" ≤5.4. Figure E.1 in Appendix E illustrates the indices for each water year for the period of record.

(b) See Appendix I for the methods used to estimate the 95% confidence intervals (CI) for the TMDL load estimates.

(c) Foe's 2003 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

(d) Domagalski (2001) reported winter mercury loads from the Sacramento Basin for WY1997 through 1999 based on data collected at Sacramento River at Freeport and Yolo Bypass at Interstate 80 (upstream of Putah Creek inputs), but did not report individual loads for the Sacramento River and Yolo Bypass.

7.1.1.2 Other Tributary Inputs to the Delta

The TotHg/flow and TSS/flow regressions for the Mokelumne-Cosumnes and San Joaquin Rivers were not significant ($P > 0.05$). Therefore, average mercury and TSS concentrations (Table 7.2) were multiplied by average annual water volumes for WY2000-2003 and WY1984-2003 (Table 6.1) to estimate an average annual load. The Mokelumne River has an estimated average annual load of 3 kg mercury and 8 Mkg TSS for WY2000-2003 and 5 kg mercury and 12 Mkg TSS for WY1984-2003 (Table 7.1). Similarly, the San Joaquin River has an average annual load of 18 kg mercury and 138 Mkg TSS and 29 kg mercury and 223 Mkg TSS, for WY2000-2003 and WY1984-2003, respectively.

Several other studies have estimated mercury and sediment loads from the San Joaquin and Mokelumne-Cosumnes watersheds (Table 7.4). All studies confirm that mercury loads from both basins are much smaller than from the Sacramento Basin (Table 7.3). Reported annual mercury loads for the San Joaquin range from 16 to 29 kg/yr. The WY1984-2003 mercury load is 29 ±4 kg/yr. This value is statistically similar to the 20-year load calculated by LWA (2002) of 26 kg/yr. Mercury load estimates for the Mokelumne-Cosumnes watersheds are smaller and range from 2 to 5 kg/yr. The WY1984-2003 load estimate is 5 ±1 kg/yr while the WY1980-1999 LWA (2002) estimate is 3 kg/yr. Again, both 20-year loading rates are statistically similar.

Sediment export rates (Table 7.4) are also much smaller for both the San Joaquin and Mokelumne-Cosumnes systems than for the Sacramento Basin (Table 7.3). Export rates for the San Joaquin varied between 110 and 235 Mkg/yr. The 20-year TMDL rate is the highest calculated for the Basin at 223±37 Mkg/yr. The Mokelumne-Cosumnes sediment yield is lower. The 20-year TMDL value is 12±3 Mkg/yr.

Mercury and TSS loads for Marsh Creek were estimated using flow at the Marsh Creek Brentwood gage. The Brentwood gage was not operational during WY2000. Therefore, the mercury and TSS loads in Table 7.1 were based on flow data for WY2001-2003. A statistically significant relationship was found for mercury/flow but not for TSS/flow. Mercury concentrations and loads were estimated using the regression, while TSS loads were computed by multiplying the 3-year average annual water volume by the average TSS concentration. The WY2001-2003 annual average mercury and TSS loads were 1 kg/yr and 1 Mkg/yr, respectively.

There are no flow gages on several small east and westside Delta tributaries: Morrison Creek, Bear Creek, Mosher Creek, French Camp Slough, and Ulatis Creek. Average wet season mercury and TSS concentrations (Table 7.2) were multiplied by estimated average annual rainfall runoff volumes (Table 6.1 and Section E.2.2 in Appendix E) to calculate an average annual load. The WY1984-2003 estimate of mercury and suspended sediment yield from the combination of all these small tributaries is 5 ±2 kg/yr and 26 ±13 Mkg/yr, respectively (Table 7.1).

Table 7.4: Comparison of Loading Estimates for Other Major Delta Tributaries

Study	**Period**	**Average San Joaquin Valley Water Year Hydrologic Index** [(a)]	**Average Annual TotHg Load** [± 95% CI] (kg)	**Average Annual TSS Load** [± 95% CI] (Mkg)
San Joaquin River @ Vernalis				
Delta TMDL [(b)]	WY2000-2003	2.7	18 ± 2	138 ± 23
	WY1984-2003	3.1	29 ± 4	223 ± 37
Foe (2003)	WY2001 [(c)]	2.2	16	110
LWA (2002)	WY1980-1999	3.5	26	na
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	210 ± 21
Mokelumne River downstream of Cosumnes River Confluence				
Delta TMDL	WY2000-2003	2.7	3 ± 1	8 ± 2
	WY1984-2003	3.1	5 ± 1	12 ± 3
Foe (2003)	WY2001 [(c)]	2.2	2	5
LWA (2002)	WY1980-1999	3.5	3	na
Eastside Tributaries (Cosumnes, Mokelumne & Calaveras Rivers & French Camp Slough)				
Delta TMDL	WY2000-2003	2.7	8 ± 2	25 ± 13
	WY1984-2003	3.1	10 ± 2	30 ± 14
Wright & Schoellhamer (2005)	WY1999-2002	2.9	na	36 ± 8

(a) Source: DWR, 2006 (http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST). DWR calculated a hydrologic index for the San Joaquin Valley (Section E.1 in Appendix E). “Normal” hydrologic conditions for the San Joaquin Valley are represented by an index value of 3.1, “wet” is ≥3.8, “dry” is 2.1 to 2.5, and “critical dry” is ≤2.1.

(b) See Appendix I for the methods used to estimate the 95% confidence intervals (CI) for the TMDL load estimates.

(c) Foe’s 2003 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.

7.1.1.3 Sacramento Basin Tributary Watersheds Loads

The Sacramento Basin accounts for about 80% of all mercury and TSS loading to the Delta (Table 7.1). Therefore, an evaluation was undertaken to determine the contribution of each of the major tributaries. The information may prove useful to help focus follow-up studies and implementation actions on key watersheds that contribute a disproportionate amount of mercury. During low flow, water in the Sacramento River at Freeport primarily originates from Shasta and Oroville Dams in the upper Sacramento and Feather River basins, respectively (Figure 7.1). In contrast, during large storms the Sacramento River at Freeport may be dominated by flows from the American and Feather Rivers. Storm overflow from the upper Sacramento River, Feather River, and Colusa Basin are routed down the Yolo Bypass. The Yolo Bypass also receives flows from Putah Creek and Cache Creek *via* the Cache Creek Settling Basin. The Cache Creek Settling Basin is located at the base of the Cache Creek watershed and currently captures about half of the sediment and mercury transported by Cache Creek (Foe and Croyle, 1998; CDM, 2004; Cooke *et al.*, 2004); untrapped sediment is flushed into the Yolo Bypass.

Four-year (WY2000-2003) and 20-year (WY1984-2003) average annual loading values were calculated for major tributaries to the Sacramento River. Table 7.5 summarizes the mercury and TSS concentration data. Table 7.6a, b, and c present watershed acreages, annual average export rates for water, mercury and TSS. The data were collected by the SRWP, DWR, USGS, CMP, and Central Valley Water Board staff (Appendix L). The water volume calculations are described in Appendix E. Appendix I provides time series plots of the available mercury and TSS data and TotHg/flow and TSS/flow regressions described in the following pages.

Total mercury and TSS concentrations for each tributary were regressed against flow to determine if correlations existed (Appendix I). The TotHg/flow and TSS/flow regressions for the American River, Cache Creek, Colusa Basin Drain, Feather River, Putah Creek and Sacramento River at Colusa were all significant ($P<0.05$) and were used to predict 4- and 20-year average annual loads (Table 7.6).

No daily flow or concentration data were available for Natomas East Main Drain (NEMD). Concentration data collected by the SRWP, USGS, and City of Roseville were available for Arcade Creek near Norwood, Del Paso Heights, and Dry Creek, all within the NEMD watershed. Wet weather concentration data for Arcade and Dry Creeks (noted in parentheses in Table 7.5) and estimated wet weather runoff for the entire Natomas East Main Drain watershed (Appendix E) were used to develop preliminary load estimates. The Sutter Bypass watershed includes the areas that drain into Butte Creek south of Chico and areas that drain into the Sutter Bypass between the Sacramento and Feather Rivers and south of the Sutter Buttes (Figure 7.1). In addition, flood flows from the Sacramento River upstream of Colusa are diverted into Sutter Bypass through the Moulton and Colusa bypasses; flood flows from the Sacramento River downstream of Colusa are diverted into the Sutter Bypass through the Tisdale bypass; and flood flows from the Feather River flow into the Sutter Bypass.

Floodwaters from the Sacramento River also spill at several locations into the Butte Creek basin and Butte Sink, which drain to Sutter Bypass. During low flow conditions, the Sutter Bypass drains through Sacramento Slough near Karnak into the Sacramento River less than a mile upstream of the Feather River confluence. During high flow, the Sacramento Slough channel is submerged and the Sutter Bypass has unchannelized flow directly into the Sacramento River. Sutter Bypass average annual water volumes and loads (Table 7.6) were estimated using flows from the DWR gage on Butte Slough near Meridian. The bypass at this location includes flows from Butte Creek and diversions from the Sacramento River made by Moulton and Colusa Weirs (which are upstream of the "Sacramento River above Colusa" sampling station), but not Tisdale Weir or other sources that discharge to the bypass downstream of Meridian. The WY1998-2003 flows were used to estimate long-term average mercury and TSS loads from Sutter Bypass, as only flows for these years are available for the Meridian gage. WY1998-2003 represents a relatively wetter period than the WY1984-2003, hence these load estimates may overestimate the Sutter Bypass contribution to the Delta.

Total mercury and TSS concentration data were available for the Sutter Bypass at Sacramento Slough near Karnak, about 30 miles downstream of the Meridian flow gage. The data were collected between February 1996 and September 2003 during a range of flow conditions, including when Sacramento Slough was submerged. There is a flow gage located nearby; however, it was operational only during the WY1996-1998 period. In addition, it was not rated for flows above 5,200 cfs (Figure 7.2); flows exceeded the 5,200 cfs rating curve happened for extended periods during each year. Therefore, the TotHg/flow and TSS/flow regressions for Sacramento Slough are based only on the samples collected when the Karnak gage recorded flows within its rating curve, most of which are low flow events. Not surprisingly, the TotHg/flow and TSS/flow regressions for Sacramento Slough were not statistically significant. Therefore, a preliminary estimate of Sutter Bypass loading was developed by multiplying water volumes recorded by the Meridian gage by the average total mercury and TSS concentrations observed at Karnak. This calculation does not address any uncertainty associated with using concentration data collected 30 miles downstream of the flow gage.

Four watersheds provided more than 90% of the annual average water volume of the Sacramento Basin during WY2000-2003 and WY1984-2003 (Table 7.6a). The watersheds are the Sacramento River above Colusa, Feather River, Sutter Bypass and American River. The 4 and 20-year water budgets balance within 4 to 5% indicating that all the major water sources have been identified. A different grouping of four watersheds contributed about 90% of the annual mercury load (Table 7.6b). The watersheds are the Sacramento River above Colusa, Cache Creek Settling Basin, Feather River and Sutter Bypass. The sum of tributary mercury inputs for both the 4 and 20-year periods is greater than the load exported to the Delta (Table 7.6b). Mercury exports average 79 to 87% of inputs. This suggests that either tributary loads are overestimated or that deposition is occurring in the river channel upstream of Freeport and/or in the Yolo Bypass.

The same four watersheds that contribute the majority of the mercury also export more than 90% of the sediment (Table 7.6c). The sum of tributary inputs of sediment is greater than the exports to the Delta. Exports range from 55% of inputs during WY2000-2003 to 89% during WY1984-2003. The results suggest, like for mercury, that incoming loads are either being overestimated or that deposition is occurring in the Central Valley. Wright and Schoellhamer (2005) also found that the Sacramento Basin landward of Rio Vista was depositional. However, unlike this report, they concluded that deposition was greater in wet than in dry periods.

Space intentionally left blank.

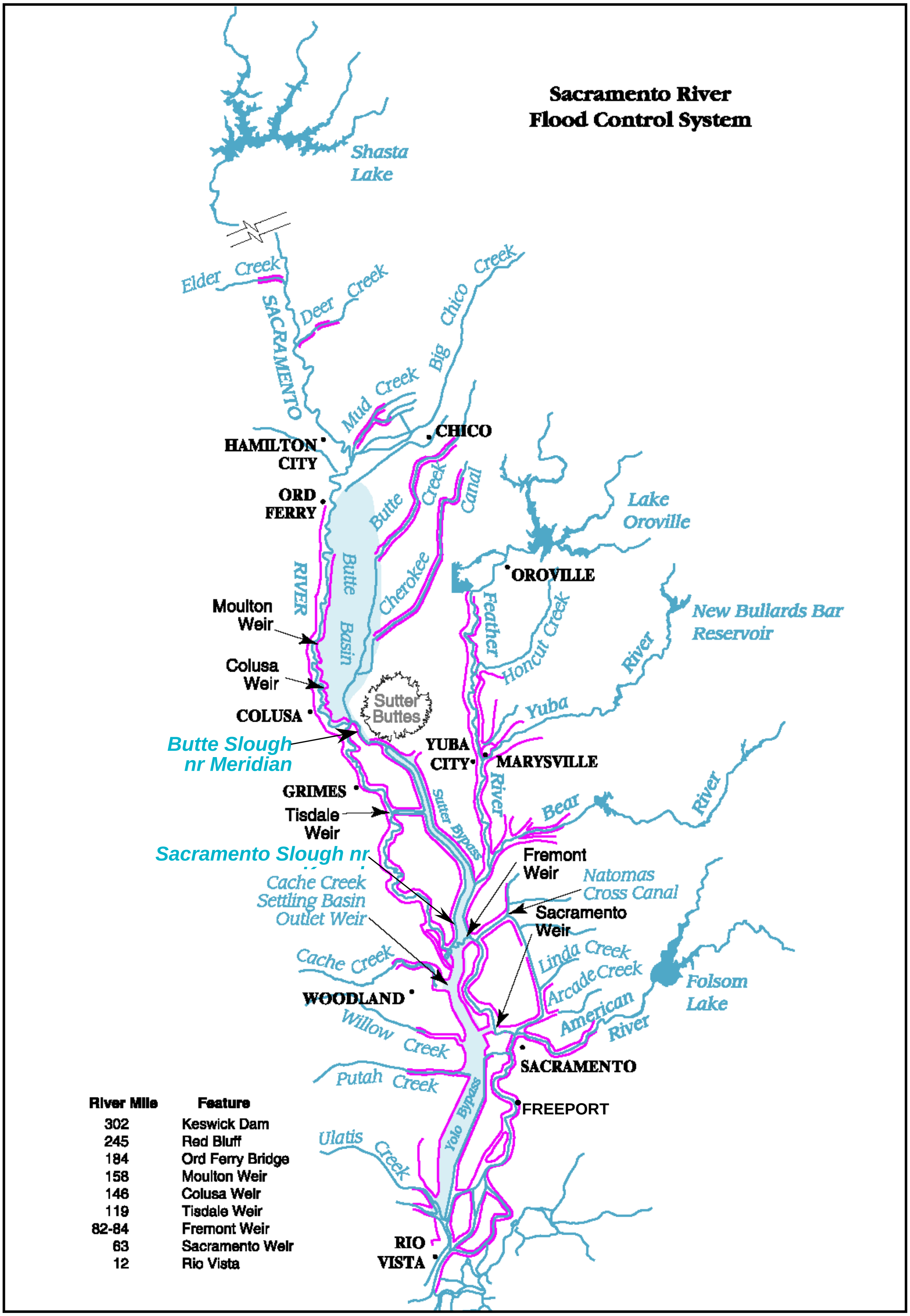

Figure 7.1: Sacramento River Flood Control System.
Pink lines represent levees. (Tetra Tech, Inc., 2005b; DWR, 2003)

Table 7.5: Total Mercury and TSS Concentrations for Sacramento Basin Tributaries.

Site	# of Samples	Sampling Begin Date	Sampling End Date	Min. Conc.	Average	Median Conc.	Max. Conc.
Total Mercury Concentrations (ng/l)							
American River @ Discovery Park	155	1/18/94	2/19/04	0.46	2.97	2.14	18.51
Cache Creek Settling Basin	26	12/23/96	2/17/04	4.07	171.89	58.24	984.60
Colusa Basin Drain	63	1/31/95	2/18/04	1.59	11.58	6.90	75.10
Feather River near Nicolaus	67	1/31/95	2/18/04	1.49	6.90	4.43	46.19
Natomas East Main Drain [a]	56 (12)	3/5/96	12/12/02	1.06 (9.52)	10.87 (27.78)	6.88 (20.84)	82.99 (82.99)
Putah Creek @ Mace Blvd.	36	1/31/95	3/09/04	1.25	33.02	9.14	485.00
Sacramento River above Colusa	64	3/10/95	2/17/04	0.60	12.30	4.27	105.16
Sacramento Slough near Karnak [b]	55	2/12/96	9/15/03	0.69	8.77	7.57	30.8
TSS Concentrations (mg/l)							
American River @ Discovery Park	191	12/15/92	2/19/04	0.5	6.23	3.0	116.0
Cache Creek d/s Settling Basin	23	12/23/96	2/17/04	41.0	425.1	140.0	1,900
Colusa Basin Drain	59	2/07/96	2/18/04	21.0	128.1	101.0	487.7
Feather River near Nicolaus	70	3/11/95	2/18/04	2.0	23.1	14.5	123.0
Natomas East Main Drain [a]	30 (8)	3/5/96	3/8/02	5.0 (16.6)	31.3 (43.0)	26.0 (34.5)	122.0 (96.0)
Putah Creek @ Mace Blvd.	29	3/28/00	2/29/04	1.6	59.01	30.0	417.8
Sacramento River above Colusa	48	3/10/95	2/17/04	10.0	98.6	36.0	662.2
Sacramento Slough near Karnak [b]	54	2/12/96	9/15/03	14.8	62.6	53.0	182.0

(a) No concentration or flow data gage data were available for Natomas East Main Drain outflows. The SRWP, USGS and City of Roseville collected total mercury and TSS concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. Wet weather concentration data for Arcade Creek and Dry Creek (noted in parentheses), and estimated wet weather runoff for the entire Natomas East Main Drain watershed (Table 6.1 in Chapter 6 and Section E.2.2 in Appendix E), were used to develop preliminary load estimates. Natomas East Main Drain was recently renamed “Steelhead Creek”.

(b) Sacramento Slough near Karnak is the low flow channel for Sutter Bypass.

Table 7.6a: Sacramento Basin Tributaries – Acreage and Water Volumes.

Tributary	Acreage	% All Acreage	Water Volume (M acre-feet/yr)		% All Water	
			WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs						
American River	1,253,740	7.5%	1.9	2.5	11%	13%
Cache Creek	724,526	4.3%	0.22	0.38	1.3%	1.9%
Colusa Basin Drain	1,577,307	9.4%	0.67	0.66	4.0%	3.4%
Coon Creek/Cross Canal	287,914	1.7%	0.089	0.094	0.5%	0.5%
Feather River	3,793,179	23%	3.9	5.3	23%	27%
Natomas East Main Drain	231,598	1.4%	0.084	0.088	0.5%	0.5%
Putah Creek	652,762	3.9%	0.041	0.11	0.2%	0.6%
Sacramento River @ Colusa	7,562,525	45%	8.2	8.1	49%	41%
Sutter Bypass	682,071	4.1%	1.8	2.3	11%	12%
Sum of Upstream Inputs:	**16,765,622**	**100%**	**16.9**	**19.5**	**100%**	**100%**
Exports to Delta						
Yolo Bypass (Prospect Slough)	- - -		1.0	2.7	6%	14%
Sacramento River (Freeport)	- - -		15.1	16.1	94%	86%
Sum of Exports to Delta:	- - -		**16.1**	**18.8**	**100%**	**100%**
Tributary Inputs – Exports to Delta:			**0.8**	**0.7**		
Exports to Delta / Tributary Inputs:			**95%**	**96%**		

Table 7.6b: Sacramento Basin Tributaries – Total Mercury Loads.

Tributary	Average Annual TotHg Load ± 95 CI [(a)] (kg/yr)		% of TotHg Inputs	
	WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs				
American River	6.4 ±0.1	14 ±0.1	2.8%	3.4%
Cache Creek Settling Basin	26 ±3	118 ±5	11%	30%
Colusa Basin Drain	10	13	4.3%	3.3%
Feather River	28 ±1	67 ±2	12%	17%
Natomas East Main Drain	2.9 ±1	3.0 ±1	1.2%	0.8%
Putah Creek	1.0 ±0	8.8 ±1	0.4%	2.2%
Sacramento River @ Colusa	139 ±4	151 ±4	60%	38%
Sutter Bypass	19 ±3	25 ±4	8.2%	6.3%
Sum of Upstream Inputs:	**232 ±6**	**400 ±8**	**100%**	**100%**
Exports to Delta				
Prospect Slough	37 ±1	169 ±5	20%	48%
Sacramento River @ Freeport	146 ±1	183 ±1	80%	52%
Sum of Exports to Delta:	**183 ±1**	**352 ±5**	**100%**	**100%**
Trib Inputs - Exports to Delta	**49**	**48**		
Exports to Delta / Trib Inputs	**79%**	**88%**		

(a) Confidence intervals (CI) were calculated for the average annual total mercury loads for the tributary stations with daily flow gages. See Appendix I for the methods used to estimate the confidence intervals.

Table 7.6c: Sacramento Basin Tributaries – TSS Loads.

Tributary	Average Annual TSS Load ± 95% CI [(a)] (MKg/yr)		% of TSS Inputs	
	WY2000-2003	WY1984-2003	WY2000-2003	WY1984-2003
Upstream Tributary Inputs				
American River	13 ±0.2	52 ±0.5	0.8%	2.4%
Cache Creek Settling Basin	68 ±6	259 ±10	4.2%	12%
Colusa Basin Drain	117	148	7.2%	7.0%
Feather River	98 ±3	216 ±6	6.0%	10%
Natomas East Main Drain	4.5 ±2	4.7 ±2	0.3%	0.2%
Putah Creek	2.2 ±0.2	16 ±1	0.1%	0.8%
Sacramento River above Colusa	1,180 ±41	1,256 ±41	73%	59%
Sutter Bypass	138 ±21	177 ±27	8.5%	8.3%
Sum of Upstream Inputs:	**1,621 ±48**	**2,129 ±49**	**100%**	**100%**
Exports to Delta				
Prospect Slough	197 ±5	1,014 ±31	22%	54%
Sacramento River @ Freeport	689 ±7	865 ±7	78%	46%
Sum of Exports to Delta:	**886 ±9**	**1,879 ±31**	**100%**	**100%**
Trib Inputs - Exports to Delta	**735**	**250**		
Exports to Delta / Trib Inputs	**55%**	**88%**		

(a) Confidence intervals (CI) were calculated for the average annual TSS loads for the tributary stations with daily flow gages. See Appendix I for the methods used to estimate the confidence intervals.

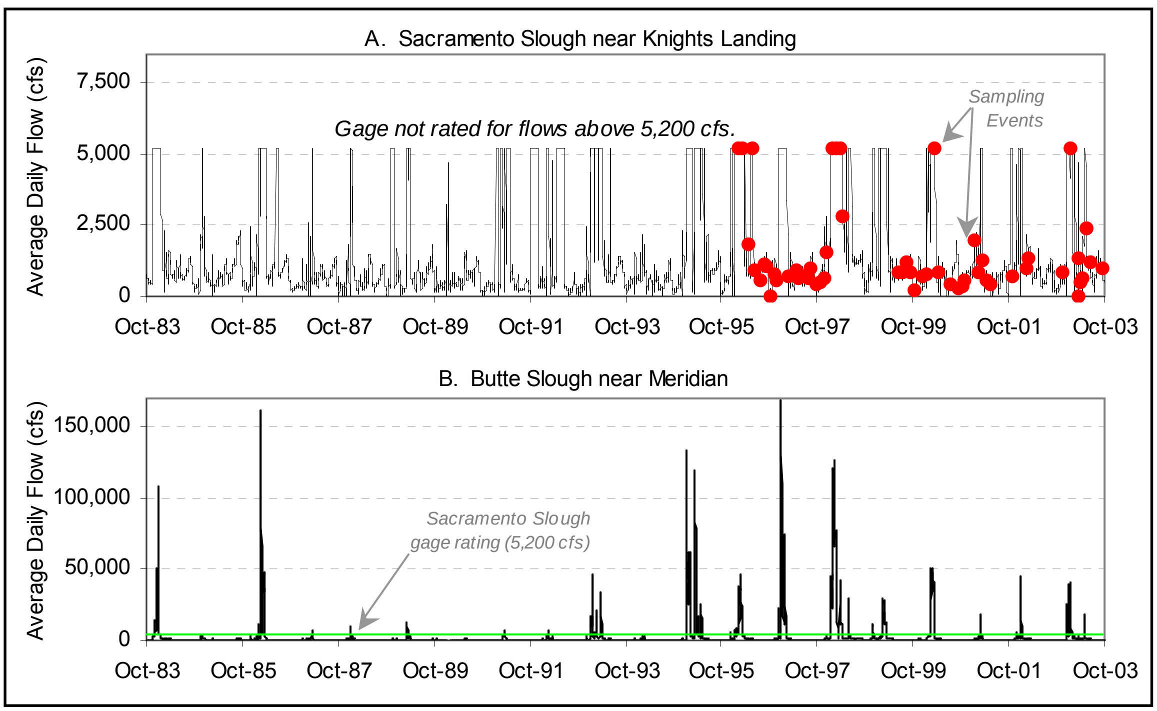

Figure 7.2: Flow Data Evaluated for Sutter Bypass.
(Note the 20-fold difference in the Y-axis flow values for these two graphs.)

7.1.2 Municipal & Industrial Sources

There are 21 NPDES-permitted municipal and industrial discharges to surface water in the Delta[40] (Figure 6.5). The sum of total mercury loads from the discharges is approximately 2.5 kg/yr, about 1% of all Delta sources (Table 7.1).

Information on average flows rates for each facility was obtained from the Central Valley Water Board's discharger project files, permits and the State Water Resources Control Board's Surface Water Information (SWIM) database. Effluent total mercury concentration data were obtained from project files and dischargers' SIP monitoring efforts.[41] Table 6.5 in Chapter 6 and Table G.1 in Appendix G provide additional information about the facilities. Table G.1 lists the estimated annual mercury loads from each facility, which were obtained from the facility-specific average effluent concentration and average daily discharge volume multiplied by 365. Appendix L provides the effluent total mercury concentration data used to calculate the average effluent total mercury loads. It was assumed that total mercury loading from the facilities does not vary substantially between wet and dry years. This consideration will be re-evaluated as additional information becomes available.

Of the 21 facilities in the Delta, two are power and heating/cooling facilities that use ambient water for cooling water: Mirant Delta LLC Contra Costa Power Plant (CA0004863) and the State of California Central Heating/Cooling Plant (CA0078581). Based on the comparison of the available intake and outfall mercury data for the Mirant Delta facility and other similar facilities that discharged to the Delta in years past (Table G.5 in Appendix G), such facilities may not act as measurable sources of mercury to the Delta. According to its NPDES permit, the Central Heating/Cooling Plant adds no chemicals to its supply water; however, the permits for Mirant Delta and other similar facilities in the tributary watersheds indicate that mercury-containing chemicals may be added to their cooling water and other low-volume waste streams may be included in their discharges (see Tables G.6 and G.7 in Appendix G). Staff recommends that the assumption that power and heating/cooling plants do not contribute mercury to Delta and upstream surface waters be re-evaluated as additional information becomes available.

---

[40] It is assumed that facility discharges contain negligible amounts of suspended solids.

[41] In September 2002, the Central Valley Water Board issued a California Water Code Section 13267 order to all NPDES dischargers (except municipal stormwater dischargers) requiring the dischargers to collect effluent and receiving water samples and to have the samples analyzed for priority pollutants contained in the U.S. Environmental Protection Agency's California Toxics Rule and portions of the USEPA's National Toxics Rule. This action was directed by Section 1.2 of the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California, also known as the State Implementation Policy (SIP), which was adopted by the State Water Resources Control Board on 2 March 2000. The SIP monitoring requires that the dischargers' mercury monitoring utilize "ultra-clean" sampling and analytical methods including Method 1669 (Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels, US EPA) and Method 1631 (Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence, US EPA). The SIP monitoring requires major industrial and municipal NPDES dischargers to collect monthly samples for metals/mercury analysis, and minor industrial and municipal NPDES dischargers to collect quarterly samples.

7.1.3 Urban Runoff

Approximately 60,000 acres in the Delta are urban, most of which are regulated by NPDES waste discharge requirements. Table 6.10 in Chapter 6 lists the permits that regulate urban runoff and their corresponding acreage. Figure 6.7 shows their locations. Urban areas not encompassed by a MS4 service area were grouped into a “nonpoint source” category.

Total mercury and TSS concentration data were collected by Central Valley Water Board staff and the City and County of Sacramento from several urban waterways within or adjacent to the Delta. Figure 6.8 shows the urban areas and sampling locations, Figure H.1 in Appendix H illustrates the wet and dry weather concentrations by location, and Appendix L provides the concentration data used in Figure H.1. Data generation by analytical methods with detection limits less than 1 ng/l began in 1996. The total mercury concentrations ranged from a dry weather low of 1.06 ng/l (Arcade Creek) to a wet weather high of 1,138 ng/l (Strong Ranch Slough). The TSS concentrations ranged from a dry weather low of less than 3 mg/l (City of Sacramento Sump 111) to a wet weather high of 1,300 mg/l (Strong Ranch Slough). A visual inspection of the total mercury and TSS data suggests that the differences between the urban watersheds are not directly related to land use. Therefore, the data were averaged by wet and dry weather for each location (Table 7.7). The averages of these location-based wet and dry weather averages are assumed to represent runoff from all urban areas in or adjacent to the Delta.

To estimate wet weather mercury and TSS loads, the average wet weather concentrations were multiplied by the runoff volumes estimated for WY2000-2003 and WY1984-2003 for each MS4 area within the Delta. To estimate dry weather mercury and TSS loads, the dry weather concentrations were multiplied by the estimated dry weather urban runoff volume. Appendix E describes the methods used to estimate wet and dry weather urban runoff from urban areas within the Delta. Wet and dry weather mercury and TSS loads were summed to estimate the WY2000-2003 average annual loadings of 2.3 kg mercury and 7.5 Mkg/yr suspended sediment and WY1984-2003 average annual loadings of 2.4 kg mercury and 7.7 Mkg/yr TSS (Table 7.8). Urban land uses comprise a small portion of the Delta and contribute about 1% of the mercury load (Table 7.1). In contrast, approximately 320,000 acres of urban land – about 42% of all urban area within the Delta source region – are within 20 miles of the Delta boundary, about one day water travel time upstream. In addition, some of the urban watersheds outside the Delta discharge via sumps into Delta waterways. These discharges were not included in the Delta urban load estimate. As a result, the urban contribution to the Delta mercury load may be underestimated. To evaluate the potential contributions from upstream urban lands, the total mercury loadings from the two MS4 service areas with the greatest urban acreage immediately outside the Delta were estimated for the WY1984-2003 period. The sum of mercury loads from the Sacramento and Stockton MS4 areas may contribute more than 2% of loading to the Delta (Table 7.9). These loads are expected to increase as urbanization continues around the Delta.

Table 7.7: Summary of Urban Runoff Total Mercury and TSS Concentrations

Urban Watershed	# of Samples	Minimum Conc.	Average Conc.	Maximum Conc.
TOTAL MERCURY (ng/l)				
DRY WEATHER				
Arcade Creek	37	1.06	8.07	34.80
City of Sacramento Strong Ranch Slough	7	3.63	18.43	84.00
City of Sacramento Sump 104	7	1.61	7.78	24.30
City of Sacramento Sump 111	7	2.16	9.59	28.96
Tracy Lateral to Sugar Cut Slough	1	7.92	7.92	7.92
Average of Location Dry Weather TotHg Averages:			**10.36**	
WET WEATHER				
Arcade Creek	14	1.73	20.90	54.30
City of Sacramento Strong Ranch Slough	13	20.10	188.32	1137.90
City of Sacramento Sump 104	14	9.94	36.72	118.42
City of Sacramento Sump 111	13	10.68	28.56	65.23
Stockton Calaveras River Pump Station	5	14.18	26.07	49.71
Stockton Duck Creek Pump Station	1	13.57	13.57	13.57
Stockton Mosher Slough Pump Station	5	9.67	14.16	17.29
Stockton Smith Canal Pump Station	4	23.17	40.97	65.87
Tracy Drainage Basin 10 Outflow	3	8.78	12.13	16.12
Tracy Drainage Basin 5 Outflow	3	7.02	12.59	20.67
Tracy Lateral to Sugar Cut Slough	3	5.44	18.10	28.45
Average of Location Wet Weather TotHg Averages:			**37.46**	
TSS (mg/l)				
DRY WEATHER				
Arcade Creek	28	5.0	31.7	122.0
City of Sacramento Strong Ranch Slough	6	5.0	9.3	15.0
City of Sacramento Sump 104	7	4.0	7.6	12.0
City of Sacramento Sump 111	7	1.5	6.2	11.0
Tracy Lateral to Sugar Cut Slough	1	26.5	26.5	26.5
Average of Location Dry Weather TSS Averages:			**16.26**	
WET WEATHER				
Arcade Creek	12	7.0	99.5	320.0
City of Sacramento Strong Ranch Slough	13	23.0	208.7	1300.0
City of Sacramento Sump 104	14	31.0	104.3	270.0
City of Sacramento Sump 111	11	15.7	92.4	340.0
Stockton Calaveras River Pump Station	5	26.0	94.3	264.6
Stockton Duck Creek Pump Station	1	281.3	281.3	281.3
Stockton Mosher Slough Pump Station	5	6.0	19.6	34.0
Stockton Smith Canal Pump Station	4	76.0	125.8	184.6
Tracy Drainage Basin 10 Outflow	3	81.1	136.9	236.0
Tracy Drainage Basin 5 Outflow	3	26.1	77.5	148.1
Tracy Lateral to Sugar Cut Slough	3	6.3	153.7	342.9
Average of Location Wet Weather TSS Averages:			**126.7**	

Table 7.8: Average Annual Total Mercury and TSS Loadings from Urban Areas within the Delta/Yolo Bypass

MS4 Permittee	WY2000-2003		WY1984-2003	
	TotHg Load (kg/yr)	**TSS Load** (Mkg/yr)	**TotHg Load** (kg/yr)	**TSS Load** (Mkg/yr)
Contra Costa County	0.60	1.9	0.62	2.0
Lathrop	0.032	0.10	0.033	0.11
Lodi	0.006	0.021	0.007	0.022
Port of Stockton	0.047	0.15	0.049	0.16
Rio Vista	0.002	0.005	0.002	0.005
Sacramento MS4 Permit Area	0.21	0.68	0.22	0.71
San Joaquin Co MS4 Permit Area	0.35	1.2	0.37	1.2
Solano County	0.019	0.062	0.020	0.065
Stockton MS4 Permit Area	0.47	1.5	0.49	1.6
Tracy	0.21	0.69	0.22	0.72
West Sacramento	0.21	0.68	0.21	0.71
Yolo County	0.050	0.16	0.051	0.17
Urban Nonpoint Source (a)	0.10	0.33	0.10	0.33
Grand Total	2.3	7.5	2.4	7.8

(a) Urban areas not encompassed by a MS4 service area were grouped into a "nonpoint source" category within each Delta subarea.

Table 7.9: Comparison of WY1984-2003 Annual Delta Mercury and TSS Loads to Sacramento and Stockton Area MS4 Loads.

MS4 Service Area (a)	**Water Volume** (M acre-feet) (b)	**TotHg Load** (kg/year)	**TSS Load** (Mkg/yr)
Sacramento MS4 Urban Total	0.19	7.4	24
Stockton MS4 Urban Total	0.026	1.0	4.0
Total Delta Inputs (c)	23	400	1,080
Stockton & Sacramento Urban Runoff as % of Total Delta Inputs	**1.0%**	**2.1%**	**1.3%**

(a) The Sacramento and Stockton Area MS4s are the two MS4 service areas with the greatest urban acreage immediately upstream of the Delta, with urban land use areas of 160,000 and 25,000 acres, respectively.

(b) Refer to Appendix E for urban runoff volume estimates for wet and dry weather, which were summed to estimate the annual average water volumes shown above.

(c) These values represent the sum of all tributary and within-Delta total mercury and TSS sources shown in Table 7.1.

7.1.4 Atmospheric Deposition

Atmospheric deposition of mercury has not been measured in the Delta. Figure 7.3 illustrates wet deposition sampling locations in northern and central California, Appendix L provides the available total mercury concentration data, and Table 7.10 summarizes the data. Volume-weighted average total mercury concentrations ranged from 4.1 ng/l at Covelo to 13 ng/l at Sequoia National Park. To estimate wet deposition, the volume-weighted average concentration observed at the North Bay/Martinez station (7.4 ng/l) was used because the station is closest to, and typically upwind of, the Delta. Total mercury loading from precipitation on surface water in the Delta (direct deposition) was estimated by multiplying the average mercury concentration in North Bay/Martinez rainwater (Table 7.10) by the average rainfall volume to fall on Delta water surfaces during WY2000-2003. Loading from runoff of mercury-contaminated rain falling on land (indirect deposition) was estimated by multiplying the average mercury concentration in rainwater by the estimated runoff volume from non-urbanized land surfaces for WY2000-2003. Runoff from urban areas was not included because it is inherently incorporated in the estimates for loading from urban runoff described in Section 7.1.3. Appendix E describes the method used to estimate rainfall runoff volumes for the Delta. Table 7.11 lists the estimated mercury loads from direct and indirect wet deposition. Wet deposition (2.3 kg/yr) contributes approximately 1% of all mercury entering the Delta (Table 7.1).

There are several uncertainties inherent in the estimates of direct and indirect wet atmospheric deposition in the Delta. For example, the concentration of mercury in rain in the Delta has not been measured and runoff coefficients have not been calculated to determine how much mercury falling on land is carried into surface water. However, these uncertainties are unlikely to have a substantial impact on the overall mercury budget for the Delta (Table 7.1) because atmospheric inputs account for only about 1% of the total mass balance.

Dry mercury deposition rates were not estimated for the Delta because there is no information on airborne particulate mercury concentrations. SFEI (2001) estimated that about five times more mercury is deposited on an annual basis in dry than in wet deposition in San Francisco Bay. If so, direct dry deposition rates in the Delta may be about 12 kg/yr or about 1 to 2% of the annual load. Dr. Gill (Texas A&M University) is currently measuring wet and dry mercury deposition rates in the Central Valley as part of CALFED project ERP-02-C06-B. The study will be completed and a report published in 2008.

In an attempt to identify local – and therefore potentially controllable – sources of mercury in atmospheric deposition in the Delta and its tributary watersheds, mercury loads emitted by facilities that report emissions to the California Air Resources Board (ARB) were reviewed. The ARB Emission Inventory Branch tracks mercury loading in air emissions in its California Emission Inventory Development and Reporting System database. ARB staff provided a database describing facilities that reported mercury emissions in 2002. Appendix J provides a summary of the types of facilities in each watershed and their estimated loads. The data indicate that almost 10 kg of mercury were released in the Delta by sugar beet facilities, electric services, paper mills, feed preparation, and rice milling. Cement and concrete manufacturing facilities and crematories in the Delta's tributary watersheds appear to have relatively high mercury emissions. These loads are not incorporated in the mass budgets because their deposition rates are not known. Local air emissions of mercury warrant additional research.

Table 7.10: Summary of Available Data Describing Mercury Concentrations in Wet Deposition in Northern and Central California.

Study [a]	Station	Volume-Weighted Average TotHg Conc. (ng/l)	# of Samples	Collection Period
San Francisco Bay Atmospheric Deposition Pilot Study (SFBADPS) [b]	North Bay	7.4	14	Aug. 1999 – Jul. 2000
	Central Bay	6.6	16	
	South Bay [c]	9.7	29	
National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDN)	San Jose [c]	10	86	Jan. 2000 – Dec. 2003
	Sequoia National Park [d]	13	5	Jul. 2003 – Dec. 2003
	Covelo [e]	4.1	60	Jan. 1998 – Sep. 2000

(a) Sources: NADP MDN – Sweet, 2000; NADP, 2004. SFBADPS – SFEI, 2001. Volume weighted average total mercury concentrations for the South Bay, Central Bay, and North Bay sites were calculated by the SFEI authors (SFEI, 2001). Volume weighted average total mercury concentrations for the San Jose, Sequoia National Park, and Covelo sites were calculated by Central Valley Water Board staff from the NADP data provided in Appendix L.

(b) The North Bay, Central Bay, and South Bay sites are located at Martinez, Treasure Island and Moffett Federal Airfield/NASA Ames Research Center near San Jose, respectively.

(c) In addition to being part of the SFBADPS, the South Bay site also became one of the NADP MDN stations. Co-location of mercury wet deposition sampling under the MDN/NADP with the Pilot Study at the South Bay site began in January 2000 and resulted in ten replicate field precipitation samples.

(d) Sequoia National Park is in the Sierra Nevada Mountains to the southeast of Fresno in the Tulare Basin, which is south of the San Joaquin Basin.

(e) Covelo is ~150 miles north of San Francisco Bay in the Coast Range.

Table 7.11: Average Annual Total Mercury Loads from Wet Deposition [a]

Period/Deposition Type [b]	WY2000-2003		WY1984-2003	
	Water Volume (acre-feet) [c]	TotHg (kg/year)	Water Volume (acre-feet) [c]	TotHg (kg/year)
Direct Deposition	88,669	0.81	91,960	0.84
Indirect Deposition	159,394	1.5	165,325	1.5
TOTAL	248,063	2.3	257,284	2.3

(a) The volume-weighted average concentration observed in the North Bay/Martinez (7.4 ng/l, Table 7.10) was used to estimate total mercury loading to the Delta.

(b) Direct deposition results from mercury-contaminated rain falling on Delta/Yolo Bypass surface waters. Indirect deposition results from runoff of mercury-contaminated rain falling on land surfaces in the Delta. Runoff from urban areas was not included because it is inherently incorporated in the estimates for loading from urban runoff described in Section 7.1.3.

(c) Refer to Appendix E for a description of the methods used to estimate rainfall runoff volumes.

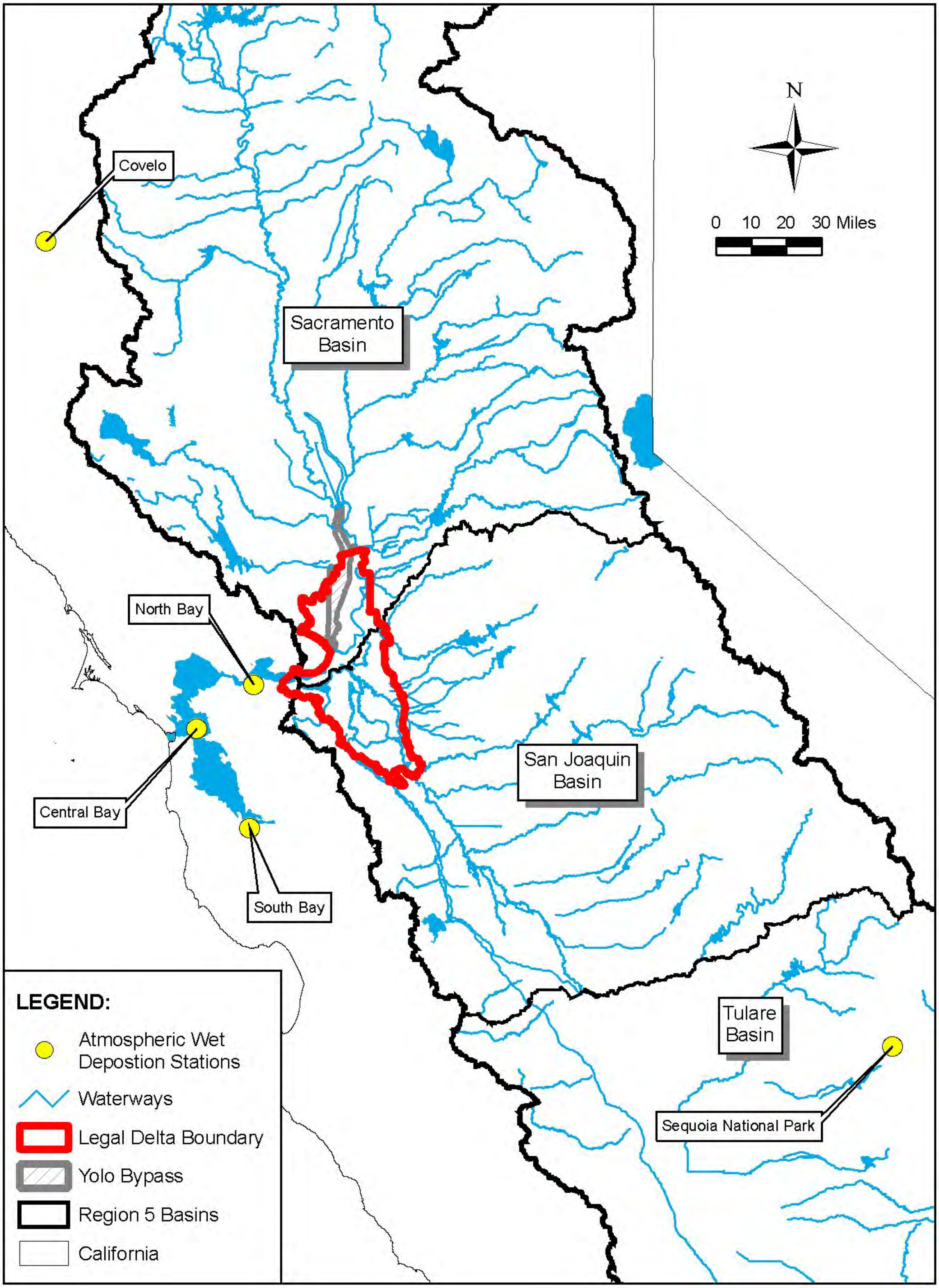

Figure 7.3: Wet Deposition Total Mercury Sampling Locations in Northern and Central California.

7.1.5 Other Potential Sources

Loading from Delta soils has not been evaluated. More than 70% of Delta lands have agricultural land uses and many of the urban areas in the Delta were once agricultural. Farming began in the Delta in 1849, about the same time that gold mining began in the Sierra Nevada Mountains (DWR, 1995). In 1861, the California legislature authorized the Reclamation District Act, which allowed drainage of Delta swampland and construction of levees; the extensive Delta levee system was mostly built between 1869 and 1880 (DWR, 1995). By 1852, hydraulic mining was the most common method for mining the placer gold deposits in the Sierra Nevada (Hunerlach *et al*., 1999) and continued until the Sawyer Decision outlawed the practice in 1884. Hydraulic gold mining resulted in the deposition of large amounts of silt and sand in Delta channels and upstream rivers (DWR, 1995). Much of these deposits may have been contaminated with mercury used to amalgamate gold. Therefore, some levees and Delta islands may have been constructed with mercury-contaminated sediment.

Barley and other grains have historically been common rotational crops in the Delta (Weir, 1952), and the seeds were treated with mercury-based fungicides before sowing (LWA, 2002). It is not known how much mercury was used in the Delta, but up to 38,000 kg of mercury may have been added in fungicides in the Sacramento Valley between 1921 and 1971 (LWA, 2002). Mercury is no longer used as an active ingredient in any pesticides (DPR, 2002).

Mercury has been measured in six soil samples in the Delta source region, mostly from agricultural fields (Bradford *et al.*, 1996). One sample was collected in the eastern Delta near White Slough north of Stockton (0.27 mg/kg) and five samples were collected within 10 miles of the Delta boundary (0.25, 0.34, and three results <0.2 mg/kg). The study authors concluded that there was no relationship between soil mercury levels and location and soil type. Some of the mercury concentrations are elevated above the proposed San Francisco Bay TMDL sediment objective of 0.2 mg/kg indicating that erosion in the Delta area may contribute to exceedances of the Bay area sediment objective.

Space intentionally left blank.

7.2 Total Mercury and TSS Losses

The following were identified as processes contributing to mercury loss in the Delta: flow to San Francisco Bay, water diversions to areas south of the Delta, removal of dredged sediments, and evasion of elemental mercury. Table 7.12 summarizes mercury and TSS losses by type.

Table 7.12: Average Annual Total Mercury and TSS Losses for WY2000-2003 and WY1984-2003.

	WY2000-2003				WY1984-2003			
	TotHg		TSS		TotHg		TSS	
	Load ± 95% CI (kg/yr)	% of All Losses	Load ± 95% CI (Mkg/yr)	% of All Losses	Load ± 95% CI (kg/yr)	% of All Losses	Load ± 95% CI (Mkg/yr)	% of All Losses
Outflow to San Francisco Bay	270 ±93	71%	930 ±283	67%	379 ±132	78%	1,309 ±398	75%
Dredging	57 ±71	15%	349	25%	57 ±71	12%	349	19%
Evasion	30	8%	- -	--	30	6%	--	--
State Water Project [(a)]	11 ±3	3%	46 ±22	3%	9 ±3	2%	38 ±18	2%
Delta Mendota Canal [(a)]	11 ±1	3%	62 ±9	5%	10 ±1	2%	60 ±9	4%
Sum of Losses	**379 ±112**	**100%**	**1,387 ±271**	**100%**	**485 ±143**	**100%**	**1,756 ±381**	**100%**

(a) The 95% confidence intervals (CI) were calculated for the State Water Project and Delta Mendota Canal loads using the method described in Appendix I.

7.2.1 Outflow to San Francisco Bay

Estimates of mercury and sediment exports from the Delta to San Francisco Bay are critical components of the Delta mercury TMDL for two reasons. First, outflow to San Francisco Bay is the primary export from the Delta and must be accurately measured to determine whether the Delta is a net source or sink for mercury and sediment. Second, the San Francisco Bay mercury TMDL assigned the Central Valley a mercury load allocation of 330 kg/yr. The allocation must be met either at Mallard Island or by a 110 kg reduction in incoming mercury loads to the Delta (Section 2.4.2.3).

Central Valley Water Board staff evaluated TSS and mercury levels in Central Valley outflows to San Francisco Bay by collecting samples at X2. Figure 6.9 in Chapter 6 illustrates a typical location of X2. Board staff conducted monthly mercury and TSS sampling at X2 from March 2000 to September 2001 (Foe, 2003) and from April 2003 to September 2003 (Appendix L). Table 7.13 and Figures I.4a and I.4b in Appendix I summarize the available total mercury and TSS concentration data for X2. Total mercury concentrations at X2 averaged 18.1 ng/l and ranged from 3.9 ng/l to 49.2 ng/l. The TSS concentrations at X2 averaged 62 mg/l and ranged from 27 mg/l to 168 mg/l. Net daily Delta outflow was obtained from the Dayflow model (Appendix E). Total mercury and TSS concentrations at X2 were regressed against Delta outflow to determine whether either could be predicted from flow. Neither regression was significant. Therefore, average mercury and TSS concentrations were multiplied by average annual water volume for WY2000-2003, WY1984-2003 and WY1995-2005 to estimate annual loads (Table 7.14). These estimates only account for advective or riverine transport and do not incorporate dispersive or tidal flux. Annual average mercury loads to San Francisco Bay were

270, 379, and 691 kg/yr for WY2000-2003, WY1984-2003 and WY1995-2000, respectfully (Tables 7.12 and 7.14).

Four studies have measured mercury and sediment loads to San Francisco Bay from the Delta (Table 7.14). The results are surprisingly variable and range from 83 to 690 kg/yr for mercury. Some of the variation is undoubtedly due to the fact that different studies have measured export rates in different hydrologic years. However, three studies estimated annual average mercury export rates for WY1995-2000. The values range between 270 ±91 and 690 ±240 kg/yr (Table 7.14). The lower two rates (270 and 440 kg/yr) may be the more accurate for several reasons. First, both incorporate estimates of tidal dispersion in their load calculations. Tidal dispersion at Mallard Island reduces export rates as incoming tides have a greater sediment and mercury concentration than outgoing ones. This reduces the net export rate and likely provides a more accurate estimate. Second, both lower rates measured mercury at Mallard Island. In contrast, the TMDL measured sediment and mercury concentrations at X2. X2 is centered at Mallard Island but moves about 10 miles up and down the estuary depending on river outflow and tidal stage. X2 measurements are appropriate for predicting biotic exposure of water column organisms, such as pelagic fish, to methylmercury. This was the primary objective of the study. However, such measurements are undoubtedly less reliable than repeated water column measurements at Mallard Island for predicting mercury and sediment transport past the island. All present studies are deficient in that they did not measure export rates during high flow. High flow is when most of the mercury and sediment is in motion.

The Delta experienced high outflow during January and February of 2006. SFEI, Central Valley and San Francisco Bay Regional Board staff collaborated on a cooperative study of mercury and sediment transport at Mallard Island. A report should be available in 2008. It is recommended, until consensus is reached on 20-year export rates at Mallard Island, that compliance with the San Francisco mercury allocation to the Central Valley be determined by monitoring Delta inputs.

Table 7.13: Summary of Total Mercury and TSS Concentration Data for X2

	# of Samples [a]	Min. Conc.	Ave. Conc.	Median Conc.	Max. Conc.
TotHg (ng/l)	20	3.95	18.10	11.59	49.20
TSS (mg/l)	20	27.0	62.41	44.50	168.0

(a) Sampling at X2 took place between March 2000 and September 2003.

Table 7.14: Estimates of Delta Exports to San Francisco Bay

Study [(a)]	Sampling Location	Period	Average Water Year Hydrologic Index [(b)]	Average Annual Water Volume (M acre-feet) [(c)]	Average Annual TotHg Load ± 95% CI (kg)	Average Annual TSS Load ± 95% CI (kg)	TotHg:TSS (mg/kg)
Delta TMDL Program X2 Calculations	X2 [(d)]	WY2000-2003	7.3	12	270 ±93	930 ±283	0.29
		WY1984-2003	7.8	17	379 ±132	1,309 ±398	
		WY1995-2000	11.0	31	691 ±240	2,384 ±726	
Foe (2003)	X2	WY2001 [(e)]	5.8	7.2	122	473	0.26
S.F. Bay TotHg TMDL (2004)	Mallard Island	WY1995-2000	11.0	31	440 ±100	1,600 ±300	0.26 ±0.08
Leatherbarrow & others (2005) [(f)]	Mallard Island	WY1999-2003	7.8	18	97 ±33	524 ±166	0.19
		WY2000-2003	7.3	12	83 ±28	450 ±140	0.18
		WY1995-2000	11.0	31	270 ±91	1,600 ±510	0.17
		WY1995-2003	9.6	24	201 ±68	1,202 ±381	0.17

(a) Sources: this report; Leatherbarrow and others, 2005; Johnson and Looker, 2004; Foe (CALFED), 2003.
(b) DWR calculated a hydrologic index for the Sacramento Valley (DWR, 2006; see Appendix E). "Normal" hydrologic conditions for the Sacramento Valley are represented by an index value of 7.8, "wet" is ≥9.2, "dry" is between 5.4 and 6.5, and "critical dry" is ≤5.4.
(c) All average annual water volumes are from the Dayflow model results for Delta outflows to San Francisco Bay.
(d) The 95% confidence intervals (CI) were calculated using the method described in Appendix I.
(e) Foe's 2003 CALFED study estimated monthly total mercury and TSS loads for March 2000 through September 2001, but did not include load estimates for November 2000. November total mercury and TSS loads for WY2001 were estimated by averaging the loads for October and December 2000.
(f) Leatherbarrow and others (2005) extrapolated total mercury loads from suspended sediment flux and suspended sediment mercury levels by adjusting for tidal dispersion and salinity, where for conductivity < 2 mS/cm, TotHg:TSS is 0.11 mg/kg, and conductivity > 2 mS/cm, TotHg:TSS is 0.29 mg/kg. Central Valley Water Board staff averaged the annual load estimates provided by Leatherbarrow and others (2005) for WY1995 through 2003 to estimate average annual loads for the periods that correspond to the San Francisco Bay mercury TMDL study period (WY1995-2000) and the Delta mercury TMDL WY2000-2003 study period. Volume-weighted TotHg:TSS ratios for each period were calculated by dividing the average annual mercury load (kg) by average annual TSS load (Mkg).

7.2.2 Exports South of Delta

Water diversions to the San Joaquin Valley and southern California account for 4 to 6% of mercury exports from the Delta and 6 to 8% of TSS exports (Table 7.12). Delta Mendota Canal (DMC) and State Water Project (SWP) exports were evaluated by collecting water samples from the DMC canal off Byron highway (County Road J4) and from the input canal to Bethany Reservoir, respectively. Bethany is the first lift station on the State Water Project canal system and is about one mile south of Clifton Court Forebay in the Delta (Figure 6.9).

Central Valley Water Board staff collected monthly total mercury and TSS samples from the DMC and SWP between March 2000 and September 2001 (Foe, 2003) and between April 2003 and 2004 (Appendix L). Table 7.15 and Figures I.4a and I.4b in Appendix I summarize the data. DMC and SWP exported water volumes were obtained from the Dayflow model (Appendix E). Total mercury and TSS concentrations were regressed against daily flow at both sites to determine whether concentrations could be predicted from flow. The regressions were not significant. Therefore, average mercury and TSS concentrations were multiplied by the WY2000-2003 and WY1984-2003 average annual water volume to estimate loads (Table 7.12).

Table 7.15: Summary of Total Mercury and TSS Concentration Data for Exports South of the Delta

Site	# of Samples [a]	Min. Conc.	Ave. Conc.	Median Conc.	Max. Conc.
Delta Mendota Canal					
TotHg (ng/l)	23	1.85	3.41	3.28	5.96
TSS (mg/l)	22	9.2	20.1	18.9	36.0
State Water Project					
TotHg (ng/l)	20	1.16	2.91	2.20	7.17
TSS (mg/l)	20	4.4	11.9	8.2	59.0

(a) Sampling of these exports took place between March 2000 and September 2003.

7.2.3 Dredging

Sediment is dredged from the Delta to maintain the design depth of ship channels and marinas. Dredge material is typically pumped to either disposal ponds on Delta islands or upland areas with monitored return-flow. Table 6.17 provides details on recent dredge projects in the Delta and Figure 6.9 shows their approximate location. The Sacramento and Stockton deep water channels have annual dredging programs; the locations dredged each year vary. Dredging occurs at other Delta locations when needed, when funds are available, or when special projects take place. Approximately 533,000 cubic yards of sediment are removed annually with about 199,000 cubic yards from the Sacramento Deep Water Ship Channel and about 270,000 cubic yards from the Stockton Deep Water Channel. Other minor dredging projects, mostly at marinas, remove an additional 64,000 cubic yards per year.

The amount of mercury removed annually by dredging was estimated by multiplying dredge volume at each project site by its average mercury concentration. Average mercury concentrations in the sediment for the project sites range from 0.04 to 0.41 mg/kg (dry weight). Two critical assumptions were made to calculate the total mercury removed from the Delta by dredging projects:

- Water content of the dredged material is 100% (50% water and 50% sediment by weight) (USACE, 2002); and
- There are about 570 kilograms of dry sediment per cubic yard of wet dredged material based on relative densities of water and sediment (Weast, 1981; Elert, 2002).

The calculations indicate that annual dredging in the Delta removes about 57 kg of mercury and 349 Mkg of sediment. This accounts for approximately 12 to 15% of all mercury exports and 19 to 25% of all sediment exports (Table 7.12). Board staff will continue to collect dredging data and evaluate the annual variability of the measurements.

7.2.4 Evasion

The loss of elemental mercury from water surfaces can be estimated on the basis of measured dissolved gaseous elemental mercury concentrations, atmospheric mercury concentrations, and estimated wind speeds (Conaway *et al.*, 2003). Conaway and others (2003) estimated summer and winter evaporation rates for San Francisco Bay. The Bay has a surface area of approximately 1.24×10^9 square meters (~306,400 acres) and is estimated to lose about 190 kg/yr of mercury to the atmosphere (Johnson and Looker, 2004). Similar estimates are not available for the Delta. However, an ongoing CALFED project (ERP-02-C06-B) is attempting to measure evasion in the Delta. The results should become available in 2008. To obtain a preliminary estimate of evasion in the Delta, it was assumed that the loss rate would be proportional to that of San Francisco Bay. The mercury lost from the Bay's surface (190 kg/year) was multiplied by the ratio of the water surface area of the Delta to that of the Bay (0.16). The result is an evasion rate of about 30 kg/yr or 6 to 8% of all mercury losses.

7.3 Total Mercury & Suspended Sediment Budgets

Delta mercury and suspended sediment assessments rely on a box model approach to approximate mass balances. Mass balances are useful because the difference between the sum of known inputs and exports is a measure of the uncertainty of the load estimates and can provide an indication of whether the Delta is depositional or erosional. The average annual water, mercury and TSS budgets for WY2000-2003 and WY1984-2003 are presented in Table 7.16.

The sum of water inputs and exports balance within 5%, indicating that all the major water sources and losses have been identified. In contrast, the mercury and TSS budgets do not balance and vary substantially depending on which estimates are used to characterize Delta outflows to San Francisco Bay. Table 7.16 incorporates the Delta TMDL Program's X2 calculations (Table 7.14), which results in mercury and TSS budgets that indicate that exports are greater than imports. This would imply that the Delta is erosional. However, this conclusion should be viewed with caution because the export rates used in the calculation are greater than those measured by others (Table 7.13) and may be biased high.[42] The Table 7.16 budget results are also in conflict with the conclusions of Wright and Schoellhamer (2005), who determined that about 65% of the sediment entering the Delta was deposited there. The mass balance calculations should be repeated once a better estimate of mercury and sediment exports at Mallard Island are determined.

[42] For example, if Leatherbarrow and others' 2005 load estimates of 83 kg/yr mercury and 450 Mkg/yr TSS are incorporated in the WY2000-2003 budget in Table 7.16, inputs would exceed exports, implying that the Delta is depositional.

Table 7.16: Water, Total Mercury and TSS Budgets for the Delta for WY2000-2003 and WY1984-2003.

	Water Volume (M acre-feet/yr)		Average Annual Load			
			WY2000-2003		WY1984-2003	
	WY2000-2003	WY1984-2003	TotHg (kg/yr)	TSS (Mkg/yr)	TotHg (kg/yr)	TSS (Mkg/yr)
Inputs	20.07	23.64	221 ±4	1,081 ±28	403 ±7	2,164 ±51
Exports	18.99	23.29	377 ±112	1,387 ±271	484 ±143	1,756 ±381
Inputs - Exports	**1.08**	**0.35**	**-156**	**-306**	**-81**	**408**
Exports ÷ Inputs	**95%**	**99%**	**170%**	**128%**	**120%**	**81%**

7.4 Evaluation of Suspended Sediment Mercury Concentrations & CTR Compliance

The evaluation of mercury contamination on suspended sediment particles for each Delta input and export site – in tandem with the source load analyses described in Sections 7.1 and 7.2 – is used to identify locations for possible remediation. The recommended total mercury control strategy described in Chapter 8 focuses on sources that have large mercury loadings and suspended sediment with high mercury concentrations, the premise being that it will be more cost effective to focus cleanup efforts on watersheds that export large amounts of highly contaminated sediment. In addition, the strategy incorporates source reductions needed to meet and maintain compliance with the CTR throughout the Delta.

7.4.1 Suspended Sediment Mercury Concentrations

Table 7.17 lists mercury to TSS ratios for Delta sources and export sites calculated using three different methods. The three approaches provide a range of particulate mercury contamination fluxing past a site. First, the ratios (in mg/kg) were estimated by dividing average annual mercury load (kg) by average annual TSS load (Mkg). This relationship is the preferred approach for Delta tributaries with statistically significant mercury and TSS relationships with flow because it provides a flow-weighted estimate. The ratio was also estimated from the slope of the regression between mercury and TSS using paired samples. This is the preferred approach for exports at Mallard Island as it is not biased by not having an accurate measure of the total export load. The least acceptable method is to take the median of the mercury to TSS ratios computed from individual paired samples. The median value tends to overemphasize low and moderate flows (the flows sampled most often) and not high flow events, which transport the majority of the suspended sediment and mercury. All three methods slightly overestimate particulate mercury (the focus of the San Francisco Bay sediment goal of 0.2 mg/kg) because none subtract the dissolved fraction from the total mercury concentration.

Table 7.17: Mercury to Suspended Sediment Ratios for Delta Inputs and Exports

	# of TotHg/TSS Paired Samples	Method A (a) TotHg Load ÷ TSS Load		Method B Linear Regression Slope for Paired TotHg/TSS (b)	Method C Median of TotHg/TSS Paired Sample Results
		WY2000-2003	WY1984-2003		
DELTA INPUTS					
Bear/Mosher Creeks	4	0.12		0.07	0.24
Calaveras River	4	0.25		0.17	0.41
French Camp Slough	4	0.70		0.63	0.30
Marsh Creek	7	0.49		0.12	0.19
Mokelumne River	20	0.37		0.37	0.42
Morrison Creek (c)	15	0.18		0.15	0.22
Prospect Slough (Yolo Bypass)	44	0.19	0.17	0.18	0.20
Sacramento River (Freeport)	134	0.21	0.21	0.17	0.24
San Joaquin River	29	0.13	0.13	0.13	0.14
Ulatis Creek	4	0.13		0.11	0.14
Urban Runoff (d)	128 (123)	0.31		0.18 (0.22)	0.35
DELTA EXPORTS					
Outflows to San Francisco Bay (X2)	20	0.29		0.30	0.28
State Water Project	19	0.24		0.18	0.29
Delta Mendota Canal	22	0.18		0.16	0.18
Dredging (e)	*8 projects*	0.19		- - -	0.03 to 0.41
TRIBUTARIES TO THE SACRAMENTO BASIN [Sacramento River + Yolo Bypass]					
American River	109	0.50	0.27	0.20	0.41
Cache Creek Settling Basin	21	0.39	0.45	0.48	0.36
Colusa Basin Drain	56	0.09		0.09	0.07
Feather River	60	0.29	0.31	0.26	0.33
Natomas East Main Drain (Arcade Ck.)	8	0.64		0.38	0.45
Putah Creek	29	0.45	0.55	0.26	0.30
Sacramento River above Colusa	47	0.12	0.12	0.12	0.11
Sutter Bypass (Sacramento Slough)	52	0.14		0.13	0.13

(a) The preferred method for each monitoring location is highlighted in gray. If total mercury concentrations and TSS concentrations both correlated well with daily flow at a given monitoring location, Method A was the preferred method for estimating suspended sediment mercury concentrations. If the available concentration data for a location were too variable and/or sparse to reliably estimate annual average suspended sediment concentrations, none of the values were highlighted. The WY1984-2003 period was evaluated only for Sacramento Basin tributaries because the other tributary loads are based on average concentrations, resulting in the same TotHg:TSS ratios for both periods.

(b) Regressions between total mercury and TSS concentrations are illustrated in Appendix I.

(c) Appendix I provides the data for each Morrison Creek sampling location.

(d) Urban runoff samples were collected at eleven locations. Methods B and C were performed between the urban runoff total mercury and TSS concentration data with and without five dramatically different sample TotHg:TSS ratios observed for Strong Ranch Slough.

(e) Sediment mercury concentrations in dredged material varied substantially across the Delta. The range of project-specific average concentrations was 0.02 to 0.77 mg/kg. The volume-weighted average mercury concentration of all the dredged material was approximately 0.19 mg/kg.

7.4.1.1 Mercury to TSS Ratios for Delta Outflows to San Francisco Bay

The San Francisco TMDL for mercury proposes a sediment objective of 0.2 mg/kg (Johnson and Looker, 2004). Mercury contamination on sediment (TotHg:TSS) in Delta outflow to San Francisco Bay averaged between 0.17 mg/kg and 0.30 mg/kg (Tables 7.14 and 7.17). The lower values are from estimates of mercury and suspended sediment loads at Mallard Island that attempt to better address tidal dispersion from Bay area. The higher values are based on measurements taken in mid channel at X2. The higher values may overestimate the degree of mercury contamination being exported from the Central Valley to San Francisco Bay. The major source of mercury and sediment to the Delta is from the Sacramento Basin. Suspended sediment ratios for the Sacramento River and Yolo Bypass range between 0.16 and 0.24 mg/kg of mercury (Table 7.17). These values are also consistent with bulk sediment concentrations in the Delta of 0.15 to 0.2 mg/kg determined by Slotton and others (2003) and Heim and others (2003). The results suggest that the contaminated sediment at X2 did not entirely originate from the Central Valley during the study period.

The X2 TotHg:TSS ratios of 0.28 to 0.30 mg/kg are similar to suspended sediment mercury concentrations of 0.33 mg/kg in San Pablo Bay (Schoellhamer, 1996) and bulk surficial sediment mercury concentrations in Suisun Bay of 0.3 to 0.35 ppm (Slotton *et al.*, 2003; Heim *et al.*, 2003). Hornberger and others (1999) report that the mercury concentration of sieved surficial sediment (<0.64 μm) in a core from Suisun Bay was 0.30 mg/kg; however, the concentration increased to 0.95 mg/kg at a depth of 30 cm. The mercury enriched zone persisted to a depth of about 80 cm before declining to a baseline concentration of 0.06 ±0.01 mg/kg. The increased mercury concentration at 30 cm was ascribed to deposition of mercury contaminated gold tailings. No current information is available on erosion rates in Suisun and Grizzly Bays but both embayments were eroding at the rate of 528 Mkg per year between 1942 and 1990 (Cappiella *et al.*, 2001). Therefore, a hypothesis is that the elevated mercury contamination on suspended sediment particles at X2 is the result of continuing erosion from Suisun Bay and possibly San Pablo Bay. Both embayments are within the legal jurisdiction of the San Francisco Bay Water Board and are part of its TMDL for mercury.

Urban runoff and almost all Delta inputs have mercury to TSS ratios greater than 0.2 mg/kg (Table 7.17). Exceptions are the San Joaquin River, Ulatis Creek, and Yolo Bypass. An evaluation of the tributary sources to the Sacramento River and Yolo Bypass indicates that all but the Sacramento River above Colusa, Sacramento Slough and Colusa Basin Drain have ratios greater than 0.2 mg/kg. A comparison of Table 7.5 and Table 7.17 indicates that several tributaries in the Sacramento Basin have high mercury to TSS ratios and large loads of mercury. Cache Creek and Feather River have high ratios and high average annual total mercury loads. This makes both attractive candidates for mercury control programs. The American River and Putah Creek also have high ratios but comparatively smaller mercury loads. In contrast, the Sacramento River above Colusa and Sacramento Slough (which receives most of its annual flows when upper Sacramento River flood waters are diverted to Sutter Bypass) have mercury to TSS ratios (0.12 and 0.13 mg/kg, respectively) comparable to background levels but high mercury loads. This is because both are transporting large amounts of sediment. The 2002 LWA report noted a similar pattern in its evaluation of median mercury to TSS ratios for the Sacramento Basin. Suspended sediment mercury concentrations between 0.03 and 0.19 mg/kg may result from a combination of erosion of background soils and atmospheric deposition from regional and global mercury sources. Therefore, the low mercury to TSS ratios for the upper Sacramento River watershed may indicate, unless site-specific hot spots are found, that very little total mercury could be removed by means other than erosion control.

7.4.2 Compliance with the USEPA's CTR

The USEPA's California Toxic Rule mercury criterion is 0.05 µg/L (50 ng/l) total recoverable mercury for freshwater sources of drinking water. The CTR criterion was developed to protect humans from exposure to mercury in drinking water and in contaminated fish. It is enforceable for all waters with a municipal and domestic water supply or aquatic beneficial use designation. This includes all subareas of the Delta. The CTR does not specify duration or frequency. As noted in Chapter 2, the Central Valley Water Board has previously employed a 30-day averaging interval with an allowable exceedance frequency of once every three years for protection of human health.

Mercury samples were not collected at a sufficiently high frequency to evaluate compliance with a 30-day average interval. Data therefore do not exist to show whether the CTR has actually been exceeded. To evaluate compliance with the CTR, regression analyses of flow and concentration were used to estimate 30-day running averages. As described in Sections 7.1.1.1 through 7.1.1.3, total mercury concentrations measured in instantaneous grab samples at Delta and Sacramento Basin tributary locations near flow gages were regressed against daily flow to determine if total mercury concentrations for days with no concentration data could be predicted. Figures 7.4 and 7.5 illustrate the regression-based 30-day running averages for locations with statistically significant ($P<0.01$) TotHg/flow correlations. Appendix I provides the TotHg/flow regressions upon which the 30-day averages are based. Table 7.18 provides a summary of the CTR compliance evaluation.

A waterway location was considered to be in compliance if its regression-based 30-day average total mercury exceeded 50 ng/l no more than once in any three-year period. Some locations had total mercury/flow regressions that were not statistically significant; also, some locations with concentration data were not near a flow gage. Such locations on larger waterways (e.g., Mokelumne River and San Joaquin River) were considered likely to be in compliance if none of the grab samples had mercury concentrations that exceeded 50 ng/l. Locations on small tributaries that typically experience short-duration, storm-related high flow events (e.g., French Camp Slough and Ulatis Creek) were considered likely to be in compliance if none of the water samples had mercury concentrations exceeding 50 ng/l, or if the exceedances occurred only during peak storm flows.

The evaluation of regression-based 30-day running average total mercury concentrations and available grab sample total mercury results indicates that all sampled locations within the Delta – except possibly Prospect Slough and Marsh Creek – are in compliance with the CTR criterion for total mercury. Although none of the grab samples collected from Marsh Creek near Highway 4 exceeded 50 ng/l total mercury, the regression-based 30-day running averages indicated that the CTR criterion might have been exceeded during one period. However, only about three years of flow data were available for the Marsh Creek location; therefore, compliance with the CTR criterion cannot be adequately determined with available data. Marsh Creek is already identified on the 303(d) List as impaired by mercury. The future mercury TMDL monitoring program for Marsh Creek will conduct another evaluation of CTR compliance as more data become available.

Evaluation of Yolo Bypass compliance with the CTR is complicated by the variety of watersheds that contribute water to it during varying hydrologic regimes. During low flow conditions, the Yolo Bypass receives flows from coastal mountain watersheds, particularly Cache Creek and Putah Creek, and other agricultural and native areas that drain directly to the bypass (Figure 7.1). During high flow conditions on the Sacramento River, excess flows from the upper Sacramento River, Sutter Bypass, Feather River, Colusa Basin, and American River watersheds may be routed down the Yolo Bypass at Fremont Weir, Sacramento Bypass and Knights Landing Ridge Cut. In a typical storm event, flows from the Cache Creek Settling Basin and other local sources reach the Yolo Bypass first, to be followed by lower concentration inputs from the Colusa Basin, Sacramento River and Feather River.

As indicated in Figure 7.4 and described in detail in Appendix E (Section E.2.2 and Figure E.3), the Yolo Bypass may not experience 30 days of continuous net outflow from Lisbon Weir upstream of Prospect Slough during dry years. In addition, storm data collected in 1995 indicate that total mercury concentrations in Prospect Slough (the primary outflow from the Bypass to the Delta) peak for a very short time. To evaluate conditions within the Bypass, the total mercury levels in tributary inputs to the Bypass were evaluated (Figure 7.5). The regression-based 30-day averages of predicted total mercury concentrations in the Sacramento River upstream of Colusa, Putah Creek and Feather River indicate that their flows are in compliance with the CTR criterion. However, the regression-based 30-day running average total mercury concentrations in Cache Creek Settling Basin outflows indicate that Cache Creek flows into the Yolo Bypass are not in compliance with the CTR criterion. This implies that when the Bypass is dominated by flows from Cache Creek, it may not be in compliance with the CTR criterion. Therefore, the Yolo Bypass area downstream of the Cache Creek Settling Basin probably does not meet the CTR criterion.

The Basin Plan Amendment for control of mercury in Cache Creek was adopted by the Central Valley Water Board in October 2005. As outlined in the Basin Plan Amendment report (Cooke and Morris, 2005), implementation actions would enable CTR compliance in outflows from Cache Creek. In order to meet the mercury loading allocation proposed for the Central Valley by San Francisco Water Board staff, the total mercury reduction strategy described in Chapter 8 assigns a 37% load reduction to mercury exports from the Feather River, American River and Putah Creek. In addition, these waterways are already identified on the 303(d) List as impaired by mercury. If future monitoring indicates that Cache Creek Settling Basin outflows to the Yolo Bypass do not comply with the CTR even after proposed total mercury reductions are achieved, and other reductions designed to accomplish safe fish tissue methylmercury levels in Cache Creek are achieved, additional reductions will be required.

Key points for the total mercury source analysis are listed after Figures 7.4 and 5 and Table 7.18.

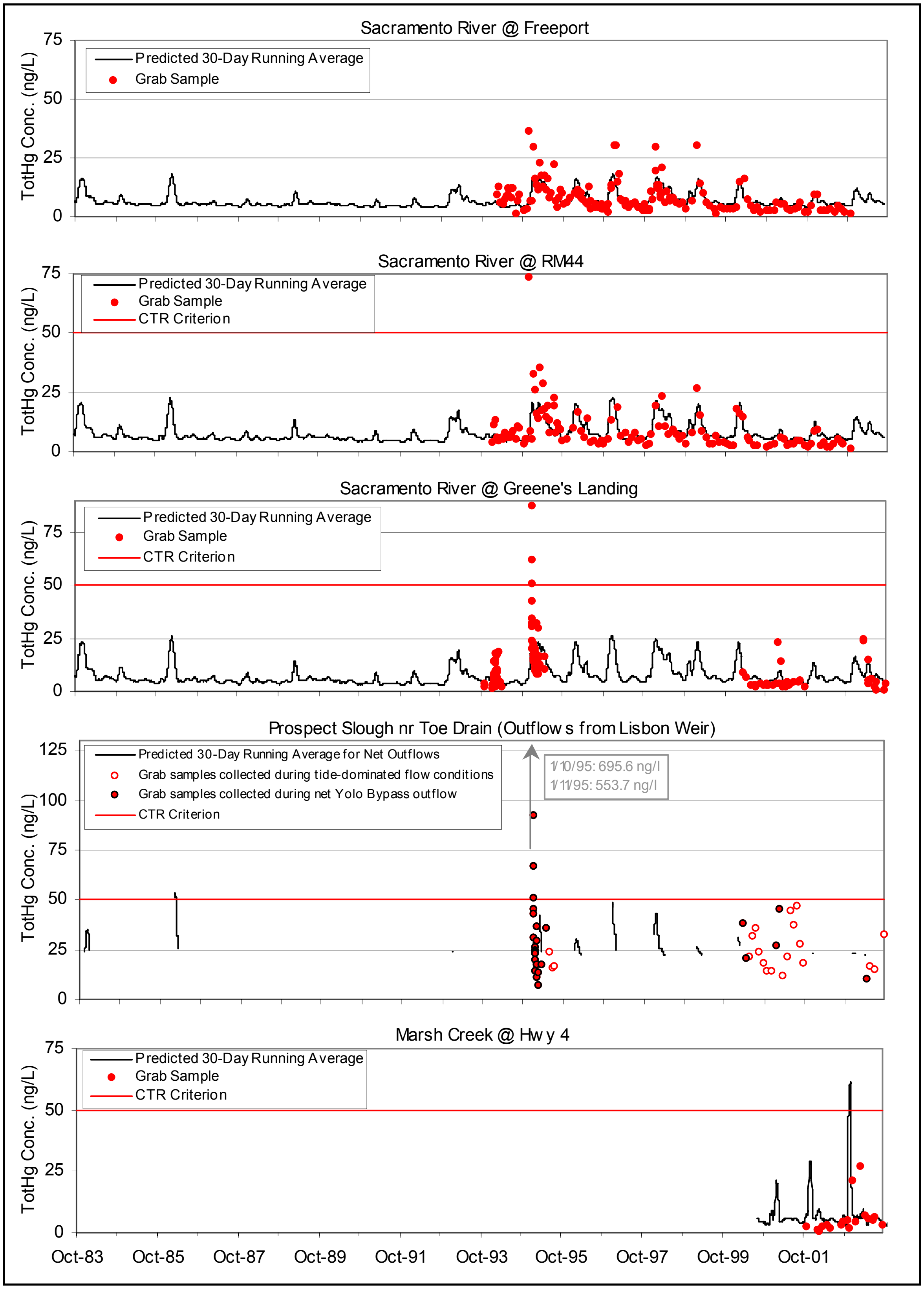

Figure 7.4: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Delta Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

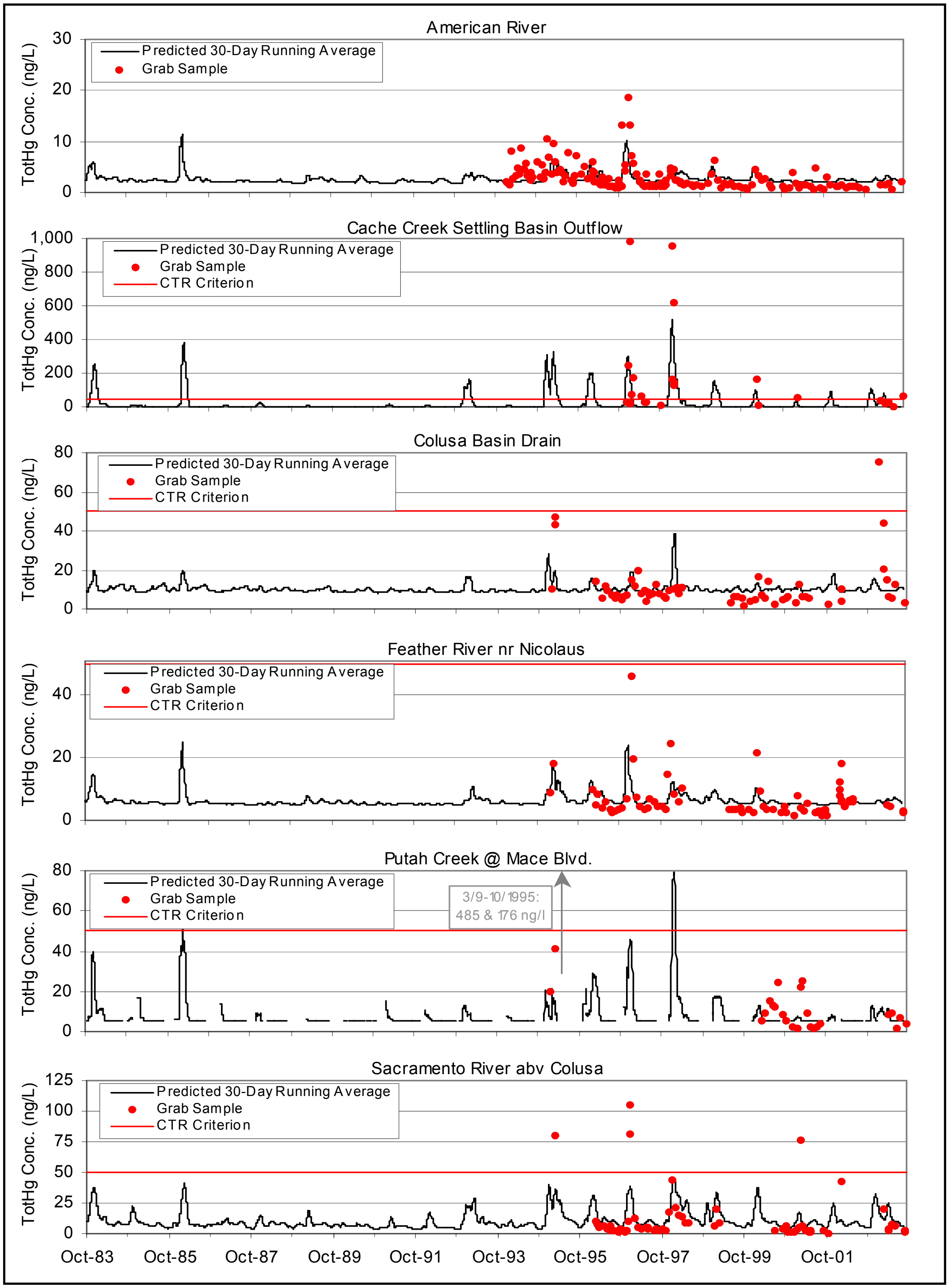

Figure 7.5: Grab Sample and Regression-Based 30-Day Running Average Total Mercury Concentrations for Sacramento Basin Tributary Locations with Statistically Significant (P<0.05) Aqueous TotHg/Flow Correlations

Table 7.18: Evaluation of CTR Compliance at Delta and Sacramento Basin Tributary Locations

Site	Is TotHg/Flow Regression Significant? [a]	Does Predicted 30-Day Average TotHg Concentration Ever Exceed the CTR (50 ng/l)? [a]	# of Grab Samples > 50 ng/l	Is the Site in Compliance with CTR?
DELTA LOCATIONS				
Bear/Mosher Creeks [b]	- - -	- - -	0	Likely Yes
Calaveras River @ RR u/s West Lane [b]	- - -	- - -	0	Likely Yes
Delta Mendota Canal	No	- - -	0	Likely Yes
French Camp Slough near Airport Way	- - -	- - -	1	Likely Yes
Marsh Creek @ Hwy 4	Yes	Once in 3 year record.	0	***Possibly Not***
Mokelumne River @ I-5	No	- - -	0	Likely Yes
Morrison Creek [c]	- - -	- - -	0	Likely Yes
Outflow to San Francisco Bay	No	- - -	0	Likely Yes
Prospect Slough (Yolo Bypass) [d]	Yes	Once [d].	5	***Possibly Not***
Sacramento River @ Freeport [e]	Yes	No.	0	Yes
Sacramento River @ Greene's Landing [e]	Yes	No.	4	Yes
Sacramento River @ RM44 [e]	Yes	No.	1	Yes
San Joaquin River @ Vernalis	No	- - -	0	Likely Yes
State Water Project	No	- - -	0	Likely Yes
Ulatis Creek near Main Prairie Rd	- - -	- - -	2	Likely Yes
SACRAMENTO BASIN TRIBUTARIES [f]				
American River @ Discovery Park	Yes	No.	0	Yes
Cache Creek d/s Settling Basin	Yes	In 11 of 20 years.	15	***No***
Colusa Basin Drain	Yes	No.	2	Yes
Feather River near Nicolaus	Yes	No.	0	Yes
Natomas East Main Drain [g]	- - -	- - -	1	Unknown
Putah Creek @ Mace Blvd. [h]	Yes	Twice, not within 3 years.	4	Likely Yes
Sacramento River above Colusa	Yes	No.	4	Yes
Sacramento Slough near Karnak [i]	No	- - -	0	Likely Yes

Table 7.18 Footnotes:

(a) Flow gage data were not available for most of the small tributary outflows to the Delta. All of the regressions for sampling locations near a flow gage were based on 20-year flow datasets except for Marsh Creek, for which only a 3-year dataset was available. Regressions were considered statistically significant for R^2 values with $P < 0.05$. Appendix I provides the regression plots.

(b) Only wet weather events were sampled on the Calaveras River and Bear and Mosher Creeks in Stockton. The one wet weather Mosher Creek sample result was combined with the Bear Creek dataset to evaluate compliance for both creeks.

(c) Concentration data collected at multiple sites on lower Morrison Creek were compiled to evaluate compliance.

(d) Sampling took place at Prospect Slough (export location of the Yolo Bypass) both when there were net outflows from tributaries to the Yolo Bypass and when there was no net outflow (i.e., the slough's water was dominated by tidal waters from the south). The regression analysis focuses only on the conditions when there was net outflow from the Yolo Bypass. Available flow information (Appendix E) indicates that during many years, the Yolo Bypass does not have a net outflow that lasts for 30 days or more.

(e) The Sacramento River sampling locations at Freeport and River Mile 44 (RM44) are upstream and downstream, respectively, of the outfall for the SRCSD WWTP. Greene's Landing is about nine miles downstream of the RM44 sampling location. Concentration data collected at all three sites were regressed against the flow data recorded at the Freeport gage, as no other gages are operational in this river reach. Appendix L provides the TotHg concentration data available for all three locations.

(f) Flows from the listed tributary watersheds may be diverted to the Yolo Bypass during high flow conditions via Knights Landing Ridge Cut, Fremont Weir and Sacramento Weir. The Coon Creek/Cross Canal watershed also contributes to the Sacramento River downstream of the Feather River but no aqueous TotHg data are available for its discharges.

(g) No concentration or flow data gage data were available for Natomas East Main Drain outflows. The SRWP, USGS and City of Roseville collected TotHg concentration data on Arcade Creek near Norwood and Del Paso Heights and Dry Creek. It was assumed that this dataset characterizes NEMD outflows.

(h) The predicted 30-day concentrations for Putah Creek are based on modeled flows (see Appendix E) estimated since the June 2006 draft TMDL Report. Although the regression between modeled flow and concentration is statistically significant ($P < 0.05$), there is greater uncertainty in the predicted 30-day concentrations. Two grab samples collected from a storm event in March 1995 and two grab samples from a storm event in February 2004 had TotHg concentrations greater than 50 ng/l: March 9 and 10, 1995: 485 and 176 ng/l; and February 18 and 25, 2004: 126 and 53 ng/l. Figure 7.5 does not illustrate grab samples collected after WY2003.

(i) Sacramento Slough near Karnak is the low flow channel for Sutter Bypass.

Key Points

- The primary sources of total mercury in the Delta include tributary inflows from upstream watersheds, atmospheric deposition, urban runoff, and municipal and industrial wastewater. Losses include flow to San Francisco Bay, water exports to southern California, removal of dredged sediments and evasion.
- The Sacramento Basin (Sacramento River + Yolo Bypass) contributed 83 to 87% of the mercury load to the Delta. Most of the material was transported during high flow.
- Present mercury exports rates to San Francisco Bay are unreliable. This precludes accurate calculations of erosion/deposition rates in the Delta and assessment of compliance with the proposed San Francisco Bay mercury allocation to the Central Valley at Mallard Island.
- The Cache Creek, Feather River, American River, and Putah Creek watersheds in the Sacramento Basin had both relatively large mercury loadings and high mercury to TSS ratios, making them attractive candidates for remediation.

8 METHYLMERCURY ALLOCATIONS, TOTAL MERCURY LIMITS & MARGIN OF SAFETY

This chapter presents recommended point and nonpoint methylmercury allocations and watershed total mercury limits for methyl and total mercury sources to the Delta. Reductions in ambient water methylmercury concentrations are required to reduce methylmercury concentrations in fish. Reductions in total mercury loads are needed to enable water and fish methylmercury reductions and to comply with the USEPA's CTR criterion for human protection and the San Francisco Bay mercury TMDL control program's total mercury allocation for the Central Valley. Section 8.1 describes the proposed methylmercury load and wasteload allocations for within-Delta and tributary inputs. Section 8.2 describes the proposed total mercury limits. Sections 8.3 and 8.4 describe the associated margin of safety and inter-annual and seasonal variability.

The methylmercury allocations and total mercury limits described in this chapter reflect the preferred implementation alternative described in Chapter 4 of the draft Basin Plan Amendment staff report and are designed to address the beneficial use impairment in all subareas of the Delta as well as in the San Francisco Bay. However, as described in the draft Basin Plan Amendment report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of allocation strategies and implementation alternatives as part of the Basin Plan amendment process.

8.1 Methylmercury Load Allocations

Since the June 2006 draft TMDL and Basin Plan Amendment staff reports issued for scientific peer review, staff made the following changes to this section in response to comments made by the scientific peer reviewers and other agencies and stakeholders:

- Developed allocations only for dischargers within the legal Delta and the Yolo Bypass (including the portion north of the legal Delta), versus the legal Delta and all dischargers within 30 miles of the legal Delta boundary.
- Provided additional explanation of, and calculations for, the proposed methylmercury allocations to more directly address expected increases in source loading from predicted population growth and wetland restoration efforts and to acknowledge the efforts of those point sources whose effluent quality demonstrates good performance.
- Changed the methylmercury allocation strategy such that all point and nonpoint sources have load-based (versus load- and concentration-based) allocations to allow for a greater range of implementation options.
- Established percent allocations for tributary inputs based on a methylmercury concentration of 0.05 ng/l (rather than 0.06 ng/l, the proposed methylmercury goal for ambient water) to reserve assimilative capacity for methylmercury flux from sediments in open-water and wetland habitats and agricultural lands, and point source discharges within the Delta/Yolo Bypass with discharge methylmercury concentrations that exceed 0.06 ng/l.

- Re-calculated all allocations based on existing methylmercury discharge concentrations rounded to two decimal places and existing methylmercury loads rounded to two significant digits.
- Re-organized the text to avoid redundancy with allocation strategy explanations provided in Chapter 4 of the draft Basin Plan Amendment staff report and to improve clarity.

8.1.1 Definition of Assimilative Capacity

A water body's loading capacity (assimilative capacity) represents the maximum rate of loading of a pollutant that the water body can assimilate without violating water quality standards. A TMDL typically represents the sum of all individual allocations of the water body's assimilative capacity and must be less than or equal to the assimilative capacity. Allocations are divided among "wasteload allocations" for point sources and "load allocations" for nonpoint sources including natural background. The TMDL is the sum of these components:

Equation 8.1:

$$\text{TMDL} = \text{Wasteload Allocations} + \text{Load Allocations}$$

For the Delta methylmercury TMDL, wasteload allocations apply to discharges from existing and future NPDES-permitted WWTPs and MS4s within the Delta and Yolo Bypass. Load allocations apply to methylmercury flux from existing and future wetland and open-water sediments and agricultural lands and atmospheric deposition within the Delta and Yolo Bypass, as well as to tributary inputs to the Delta/Yolo Bypass. Natural background sources include atmospheric deposition, methylmercury flux from wetland and open-water sediments, and runoff from upland areas that existed prior to human-related pollution emissions such as mercury-contaminated sediment from historical mining activities in the tributary watersheds, mercury emissions from local and international industrial and municipal sources, and water management activities. Natural background sources are incorporated in the load allocations for wetlands, open water, and atmospheric deposition because data were not available to distinguish between natural background and nonpoint sources.

A TMDL need not be stated as a daily load (Code of Federal Regulations, Title 40, §130.2[i]). Other measures are allowed if appropriate. The methylmercury allocations proposed in Table 8.4 at the end of Section 8.1.3 are expressed in terms of average annual loads because the adverse effects of mercury occur through long-term bioaccumulation. The allocations are intended to represent annual averages and account for both seasonal and long-term variability. The annual load and wasteload allocations can be expressed in daily terms by simply dividing each allocation by 365.[43] However, to best attain and maintain the proposed fish tissue objectives, staff recommends that the allocations be implemented as average annual loads.

Methylmercury allocations were made in terms of the existing assimilative capacity of each of the different Delta subareas. A methylmercury TMDL must be developed for each Delta subarea because the sources and percent reductions needed to meet the proposed

[43] In its November 2006 memorandum concerning appropriate time increments for TMDLs, the USEPA recommended that States provide written documentation regarding how the TMDL allocations can be expressed in daily terms (USEPA, 2006).

implementation goal are different in each subarea. The linkage analysis (Chapter 5) described the calculation of an implementation goal for methylmercury in ambient water that is linked to the fish tissue methylmercury targets. The recommended implementation goal is an annual average concentration of 0.06 ng/l methylmercury in unfiltered water. This goal describes the assimilative capacity of Delta waters in terms of concentration (Section 5.2). Central Valley Water Board staff anticipates that as the average concentration of methylmercury in each Delta subarea decreases to the safe aqueous goal, then the targets for fish tissue will be attained. To determine necessary reductions, the existing average aqueous methylmercury levels in each Delta subarea were compared to the methylmercury goal (Table 8.1).

The amount of reduction needed in each subarea is expressed as a percent of the existing concentration. As noted in the linkage analysis, the aqueous methylmercury goal was developed using water data for March to October 2000 because this was the only period for which there was overlap between water data and the lifespan of the fish. Table 8.1 compares the proposed goal to average methylmercury concentrations for March to October 2000 (Scenario A) and for March 2000 to April 2004 (Scenario B). Scenario B is based on a much larger dataset and includes values for all seasons. However, the percent reductions are similar for both scenarios and range from 0 to 80% for the different subareas. Therefore, staff recommends the use of the proposed reductions listed in Scenario B for the calculation of assimilative capacity.

The assimilative capacity of each subarea (Table 8.2) was determined using the proposed reductions listed in Scenario B in Table 8.1 (except for the Central and West Delta subareas, as discussed in the next paragraphs), the sum of existing annual methylmercury inputs from identified sources (see Table 8.4 at the end of Section 8.1.3) and the following equation:

Equation 8.2: *(using the Sacramento subarea as an example)*

$$\begin{array}{c}\text{Assimilative}\\ \text{Capacity (g/yr)}\end{array} = \begin{array}{c}\text{Existing MeHg}\\ \text{Inputs (g/yr)}\end{array} - \left[\begin{array}{c}\text{\% Reduction Needed to}\\ \text{Meet Proposed Goal}\end{array} * \begin{array}{c}\text{Existing MeHg}\\ \text{Inputs (g/yr)}\end{array}\right]$$

$$= 2{,}418 \text{ g/yr} - (44\% * 2{,}418 \text{ g/yr})$$

$$= 1{,}354 \text{ g/yr}$$

The subareas on the eastern boundary of the Delta require substantial reductions in fish and aqueous methylmercury levels. In contrast, ambient methylmercury concentrations in the Central and West Delta subareas equal or approach the proposed aqueous methylmercury goal of 0.06 ng/l, resulting in the need for little-to-no reductions in methylmercury inputs to these subareas. Because water quality in the Central and West Delta subareas is dominated by inflows from upstream Delta subareas that require reductions ranging from 44 to 80%, Central and West Delta fish tissue and ambient water methylmercury levels are expected to decrease when actions are implemented to reduce up-basin water methylmercury levels. In addition, the primary within-subarea source of methylmercury in the Central and West Delta subarea is flux from open water habitat sediments (Table 8.4). Therefore, staff recommends that no reduction be required for point and nonpoint source methylmercury discharges within the Central and West Delta subareas. Section 8.1.2 describes an allocation strategy that ensures that fish and water methylmercury concentrations in these subareas remain in compliance with the proposed fish tissue objectives and methylmercury goal for water.

The following two sections describe the strategy and calculations used to determine specific allocations for point and nonpoint sources listed in Table 8.4 for each of the subareas.

Table 8.1: Aqueous Methylmercury Reductions Needed to Meet the Proposed Methylmercury Goal of 0.06 ng/l. [(a)]

	Delta Subarea						
	Central Delta	Marsh Creek	Mokelumne River	Sacramento River	San Joaquin River	West Delta	Yolo Bypass
A. Scenario Based on March to October 2000 Aqueous MeHg Data [(b)]							
Average Aqueous MeHg Concentration (ng/l)	0.055	0.224	0.140	0.120	0.147	0.087	0.305
Percent Reduction Needed to Meet the Proposed MeHg Goal	0%	73%	57%	50%	59%	31%	80%
B. Scenario Based on March 2000 to April 2004 Aqueous MeHg Data [(b)]							
Average Annual Aqueous MeHg Concentration (ng/l)	0.060	0.224	0.166	0.108	0.160	0.083	0.273
Percent Reduction Needed to Meet the Proposed MeHg Goal	0%	73%	64%	44%	63%	28%	78%

(a) The amount of reduction needed in each subarea is expressed as a percent of the existing methylmercury concentration. For example, the percent reduction needed for the Marsh Creek subarea Scenario A is calculated by: (0.244 - 0.06) / 0.244 = 73%. The average March to October 2000 methylmercury concentration for the Central Delta is below the proposed implementation goal of 0.06 ng/l. As a result, Scenario A calculations for the Central Delta result in negative numbers: A(1): (0.055 - 0.06)/0.055 = -9%. No reduction is needed under Scenario A or B for Central Delta ambient methylmercury.

(b) Average concentrations are based on unfiltered MeHg concentration data collected at the following locations: Delta Mendota Canal and State Water Project (Central Delta); Marsh Creek at Highway 4; Mokelumne River near I-5; Sacramento River at Freeport, RM44 and Greene's Landing; San Joaquin River near Vernalis; outflow to San Francisco Bay measured at X2, usually near Mallard Island (West Delta); and Prospect Slough near Toe Drain (Yolo Bypass). The values for the Central Delta, Mokelumne River, Sacramento River, San Joaquin and West Delta subareas are described in Section 5.1 and Table 5.1 in Chapter 5 and are based on monthly average concentrations so that the average concentrations for each study period are not influenced by the unequal number of samples collected in each month. The Yolo Bypass average concentrations also are based on monthly average concentrations. The sampling frequency on Marsh Creek was inadequate to develop averages for each study period, much less to pool data by month; therefore, the average of all available concentration data was used in both scenarios. The Yolo Bypass and Marsh Creek data are described in Chapter 6, Section 6.2.1 and Table 6.3. It was assumed that the sampling locations are representative of the subareas in which they occur.

Table 8.2: Assimilative Capacity Calculations for Each Delta Subarea.

Delta Subarea	Existing Average Annual MeHg Conc. [a] (ng/l)	% Reduction Needed to Achieve Proposed Goal of 0.06 ng/l [a]	Existing Annual MeHg Load from Identified Sources [b] (g/yr)	Assimilative Capacity (g/yr)
Central Delta	0.060	0%	668	668
Marsh Creek	0.224	73%	6.1	1.6
Mokelumne River	0.166	64%	146	53
Sacramento River	0.108	44%	2,474	1,385
San Joaquin River	0.160	63%	528	195
West Delta	0.083	0%	330	330
Yolo Bypass [North & South]	0.273	78%	1,069	235

(a) No percent reductions are proposed for the Central and West Delta subareas because their fish tissue and aqueous methylmercury levels either currently achieve or are expected to achieve safe levels when actions are implemented to reduce upstream aqueous methylmercury levels. Proposed reductions for other subareas are from Table 8.1 Scenario B.

(b) "Existing Annual MeHg Load" represents the sum of all identified inputs to each subarea (Chapter 6 and Table 8.4).

8.1.2 Allocation Strategy

Table 8.4 at the end of Section 8.1.3 lists wasteload and load allocations for each point and nonpoint methylmercury input by subarea and reflects the preferred implementation alternative and resulting allocation strategy described in Chapter 4 of the draft Basin Plan Amendment staff report. This section summarizes the preferred allocation strategy developed in the draft Basin Plan Amendment staff report. Section 8.1.3 describes the equations used to calculate the individual allocations.

The available science is adequate to establish individual allocations for point sources in the Delta/Yolo Bypass and tributary inputs to the Delta/Yolo Bypass, and general (subarea) methylmercury allocations for nonpoint sources within the Delta/Yolo Bypass. The preferred allocation strategy specifies the following:

- Atmospheric deposition and discharges from urban areas outside of MS4 service areas[44] in all Delta subareas have load allocations set at their existing average annual methylmercury loads.
- All point and nonpoint sources in the Central and West Delta subareas have wasteload and load allocations set at their existing average annual methylmercury loads to ensure that compliance with the fish tissue objectives is maintained.
- Methylmercury flux from sediments in open-water habitats in all Delta subareas have load allocations set at their existing average annual methylmercury loads, except where open-water methylmercury production must be reduced to achieve the proposed fish tissue objectives (e.g., the Yolo Bypass and Marsh Creek subareas).
- Wasteload and load allocations integrate expected expansions to existing sources and new sources.

[44] As described in Chapter 4 of the draft Basin Plan Amendment staff report, if such urban communities expand significantly, or are found to be significant contributors of methylmercury or other pollutants, they could be designated Phase II MS4 dischargers and required to develop and implement sediment and/or mercury control plans like those proposed for existing Phase II dischargers.

- Waste load allocations acknowledge the efforts of those point sources whose effluent quality demonstrates good performance, and require improvement by other dischargers.

Anticipated population growth, regional water management changes, and wetland restoration efforts could result in increases in methylmercury loading to the Delta. For example, increasing populations will result in increasing total mercury and methylmercury discharges from municipal WWTPs and urban runoff. The California Department of Finance predicts that populations in the Delta/Yolo Bypass counties[45] will increase 76% to 213% by 2050 (CDOF, 2007), with an average increase of about 120%. (For more discussion on potential regional changes, see Section 8.4.3, "Regional and Global Change".)

The allocations for each existing source apply to the sum of its existing discharge and any expansion to its discharge in the future. The recommended open-water and wetland methylmercury allocations apply to all wetlands and open-water habitat acreage in each Delta subarea, including current wetlands and future wetland restoration projects. MS4 allocations apply to all urban acreage within MS4 service areas within each Delta subarea and similarly address loading from current and future urban areas within the MS4 service areas.

Staff assumed that, in general, NPDES-permitted WWTP discharges throughout the Delta/Yolo Bypass would increase by 120%. Staff assumed that half of that growth will be addressed by expansions to existing facilities in each Delta subarea, and that the remaining half will be serviced by new facilities in each subarea. Table 8.3 illustrates current WWTP effluent volumes discharged to each Delta subarea, the amount of discharge volume increase expected in each subarea, and the discharge volume that staff assumed will be addressed by existing and new facilities.

Results from methylmercury monitoring by NPDES facilities in the Delta and upstream tributary watersheds indicate that many facilities have average effluent methylmercury levels that approach or are less than the proposed implementation goal for unfiltered methylmercury in Delta waters (0.06 ng/l), while other facilities have much higher methylmercury levels (see Chapter 6 and Appendix G in the TMDL Report and Bosworth *et al*., 2008). This indicates that some discharges, though they contribute methylmercury loading to the Delta, may act as dilution because of their low methylmercury concentrations.

Staff recommends that source discharges with average methylmercury concentrations below the proposed aqueous methylmercury goal of 0.06 ng/l be considered dilution and assigned a wasteload allocation based on their existing discharge methylmercury concentration. There are five NPDES-permitted discharges that have methylmercury concentrations less than 0.06 ng/l: Brentwood WWTP, Deuel Vocational Institute WWTP, Oakwood Lake Subdivision Mining Reclamation, West Sacramento WWTP, and Woodland WWTP. The "Concentration Used to Calculate Allocation" in Table 8.4 for these sources was set at the existing discharge methylmercury concentration for each of these dischargers.

[45] The CDOF predicts the following population increases by 2050: Contra Costa County - 89%, Sacramento County - 76%, San Joaquin County - 213%, Solano County - 105%, and Yolo County - 93% (CDOF, 2007).

Conceptually, there is no need to limit the loading from sources that act as dilution, given the overall extent of impairment throughout the Delta. However, to enable the calculation of allocations required for other sources, load-based allocations must be calculated even for those sources that act as dilution. Staff assumed that the four municipal WWTPs with discharges less than 0.06 ng/l would increase their discharge volume by 60% to account for future population growth. Staff calculated their methylmercury wasteload allocations shown in Table 8.4 by multiplying their existing average effluent methylmercury concentrations by their current discharge volumes (shown in Table 8.3) multiplied by 160%. Staff also calculated "Unassigned WWTP allocations" in Table 8.4 for each subarea to address new WWTP discharges. Staff assumed that new WWTPs would be designed to discharge effluent with methylmercury concentrations equal to or less than 0.06 ng/l, and calculated the "Unassigned WWTP allocations" by multiplying the predicted volumes shown in Table 8.3a by 0.06 ng/l methylmercury.

To calculate allocations for WWTPs with effluent methylmercury concentrations greater than 0.06 ng/l, staff used the existing effluent volumes rather than multiply the existing volumes by 160%. Although these facilities may need to increase their discharged effluent volumes in response to population growth in their service areas, increased effluent volumes at their existing effluent concentrations, if allowed, would worsen the methylmercury impairment. Conceptually, discharge volume from a WWTP that has an average effluent methylmercury concentration greater than 0.06 ng/L could be allowed to increase so long as its methylmercury load does not increase. [46]

This approach is consistent with State Water Board Resolution No. 2005-0060,[47] which required the San Francisco Bay Water Board to incorporate provisions that acknowledge the efforts of those point sources whose effluent quality demonstrates good performance, and require improvement by other dischargers, when establishing waste load allocations.

To calculate load allocations for tributary inputs to Delta subareas that require methylmercury source reductions, staff recommends that the tributary inputs be assigned percent allocations based on a methylmercury concentration of 0.05 ng/l (rather than 0.06 ng/l, the proposed methylmercury goal for ambient water). Such an allocation strategy would ensure that assimilative capacity is reserved for methylmercury flux from sediments in open-water and wetland habitats, and agricultural and point source discharges within the Delta/Yolo Bypass with discharge methylmercury concentrations that exceed 0.06 ng/l.

[46] Discharge volume from a WWTP that has average effluent methylmercury concentrations greater than 0.06 ng/l could be allowed to increase so long as its load does not increase above its wasteload allocation. For example, an increase in volume would necessitate a decrease in methylmercury concentration to maintain the load allocation so that the increased volume does not cause an increase in receiving water methylmercury concentration. If an offset program is developed, another option could be for such a WWTP to compensate for increases in its load by completing offset projects upstream.

[47] On September 7, 2005, the State Water Board adopted Resolution No. 2005-0060 ("Remand Order") remanding the San Francisco Bay Water Board's San Francisco Bay Mercury TMDL Amendment with requirements for specific revisions to the TMDL and associated implementation plan.

Table 8.3a: Total Existing Municipal WWTP Effluent Volume Discharged to Each Delta Subarea, Predicted Increases Due to Population Growth, and Volumes and Methylmercury Loads Predicted to Be Discharged by New WWTPs.

Subarea	**Existing Effluent Volume** (mgd) [(a)]	**Predicted Increase** (mgd) [(b)]	**Effluent Volume Predicted to Be Discharged by New WWTPs** (mgd) [(c)]	**Effluent MeHg Load Predicted to Be Discharged by New WWTPs** (g/yr) [(d)]
Central Delta	6.1	7.3	3.7	0.31
Marsh Creek	3.1	3.7	1.9	0.16
Sacramento River	170	204	102	8.5
San Joaquin River	43	52	26	2.2
West Delta	0 [(e)]	6.9 [(e)]	6.9 [(e)]	0.57
Yolo Bypass	8.5	10.2	5.1	0.42

(a) "Existing Effluent Volume" is the sum of effluent volumes discharged by municipal WWTPs in each Delta subarea.
(b) Staff assumed that, in general, NPDES-permitted WWTP discharges throughout Delta/Yolo Bypass would increase by 120% in response to predicted population growth in the region.
(c) Staff assumed that half of the predicted 120% population growth would be addressed by expansions to existing facilities in each Delta subarea, and that the remaining half would be serviced by new facilities in each subarea. Staff predicted discharge volumes to be serviced by new WWTPs by multiplying the "Existing Effluent Volume" discharged to each subarea by 0.6.
(d) New WWTPs' discharge methylmercury loads were calculated by multiplying the predicted effluent volumes by 0.06 ng/l methylmercury.
(e) There are no WWTPs currently discharging in the West Delta subarea. However, the Ironhouse Sanitary District has submitted a Report of Waste Discharge, dated 11 June 2007, and applied for a NPDES permit authorization to discharge up to 4.3 mgd of treated wastewater from the Ironhouse Sanitary District WWTP to the San Joaquin River within the West Delta subarea. The WWTP will likely begin discharging to the San Joaquin River sometime in 2009. Staff calculated the "Predicted Increase" and "Effluent Volume Predicted to Be Discharged by New WWTPs" for the West Delta subarea by multiplying 4.3 mgd by 0.6 and adding the result (2.6 mgd) to 4.3 mgd, for a total of 6.9 mgd.

Table 8.3b: Predicted Effluent Volumes Used to Calculate Corresponding Methylmercury Loads for Municipal WWTPs that Currently Discharge Effluent with Average Methylmercury Concentrations Less than 0.06 ng/l.

Permittee [(a)]	**NPDES Permit No.**	**Existing Effluent Volume** (mgd)	**Predicted Effluent Volume Used To Calculate MeHg Loads for Allocations in Table 8.4** [(a)] (mgd)
Brentwood WWTP	CA0082660	3.1	5.0
West Sacramento WWTP	CA0079171	5.6	9.0
Deuel Vocational Inst. WWTP	CA0078093	0.47	0.75
Woodland WWTP	CA0077950	6.05	9.7

(a) Staff assumed that, in general, NPDES-permitted WWTP discharges throughout Delta/Yolo Bypass would increase by 120% in response to predicted population growth in the region. Staff assumed that half of the population growth would be addressed by expansions to existing facilities in each Delta subarea, and that the remaining half would be serviced by new facilities in each subarea. Discharges from WWTPs with effluent methylmercury concentrations less than 0.06 ng/l act as dilution. Staff recommends that these facilities be assigned allocations calculated using their existing effluent methylmercury concentrations. To determine loads for use in Table 8.4, discharge volumes for these WWTPs were multiplied by 160% to allow for volume and load increases due to predicted population growth.

8.1.3 Percent Allocation Calculations

As described in the previous section, the following sources have allocations set equal to 100% of their existing methylmercury loads: atmospheric deposition, discharges from urban areas outside of MS4 service areas, methylmercury flux from open-water habitat sediments (except in the Yolo Bypass and Marsh Creek subareas), and all point and nonpoint sources in the Central and West Delta subareas. In addition, WWTPs with effluent concentrations less than the proposed methylmercury goal for ambient water have wasteload allocations set equal to 160% of their existing loads.

As noted in Section 6.2.3, two of the facilities in the Delta are power or heating/cooling facilities that use ambient water for cooling water, Mirant Delta LLC Contra Costa Power Plant and the State of California Heating/Cooling Plant. Methylmercury loads and concentrations in heating/cooling and power facility discharges vary with intake water conditions; the facilities do not appear to act as a source of methylmercury to the Delta. Staff recommends that these facilities have concentration-based allocations equal to 100% of their intake methylmercury concentrations, such that their discharge allocations equal the detected methylmercury concentration found in their intake water. Outflows from these facilities were not incorporated in the allocation calculations for other sources and are not listed in Table 8.4. GWF Power Systems (CA0082309), in the West Delta subarea, acquires its intake water from sources other than ambient surface water and therefore was incorporated in the allocation calculations. GWF effluent methylmercury concentrations are less than the analytical method detection limit (0.03 ng/l; see Table 6.5 in Chapter 6). As a result, staff recommends that its allocation be equal to an annual load of 0.0052 g/yr, calculated by using the methylmercury method detection limit (0.03 ng/l) and GWF's design flow (0.125 mgd) to accommodate potential growth.

Discharge methylmercury data were not available for the Metropolitan Stevedore Company (CA0084174), a marine bulk commodity terminal on leased land at the Port of Stockton in the Central Delta subarea. Staff recommends that a methylmercury wasteload allocation for non-storm water discharges from the Metropolitan Stevedore Company be established in its NPDES permit once it completes at least three sampling events for methylmercury in its discharges. Its wasteload allocation will be a component of the "Unassigned WWTP Allocation" for the Central Delta subarea.

The following equation was used to determine the percent allocations for all other point and nonpoint sources needed to achieve the assimilative capacity in each Delta subarea:

Equation 8.3: *(using the San Joaquin subarea as an example)*

Percent Allocation =

$$= \frac{\text{Assim. Cap.} - \text{Sum (Allocations for Atm. dep., Open water, Nonpt urban, \& Sources w/ Ave. MeHg Conc.} \leq 0.06 \text{ ng/l)}}{\text{All existing loads} - \text{Sum (Existing loads for Atm. dep., Open water, Nonpt urban, \& Sources w/ Ave. MeHg Conc.} \leq 0.06 \text{ ng/l)}}$$

$$= \frac{195 \text{ g/yr} - (2.7 \text{ g/yr} + 48 \text{ g/yr} + 0.0022 \text{ g/yr} + 0.021 \text{ g/yr} + 0.38 \text{ g/yr} + 110 \text{ g/yr} + 3.9 \text{ g/yr} + 2.2 \text{ g/yr})^{\star}}{528 \text{ g/yr} - (2.7 \text{ g/yr} + 48 \text{ g/yr} + 0.0022 \text{ g/yr} + 0.013 \text{ g/yr} + 0.38 \text{ g/yr} + 356 \text{ g/yr} + 11 \text{ g/yr})}$$

$$= 25\%$$

⋆ Explanation: *As shown in Table 8.4e, allocated methylmercury loads for atmospheric deposition, open water, and nonpoint urban runoff were set at existing levels. Deuel Vocational Institute WWTP* *and Oakwood Lake Subdivision Mining Reclamation have average discharge methylmercury concentrations less than 0.06 ng/l, and existing annual loads of 0.013 g/yr and 0.38 g/yr, respectively. Both are assigned allocations based on their existing methylmercury concentrations. The Deuel Vocational Institute WWTP's corresponding load of 0.021 g/yr incorporates a percent allocation of 160%. The San Joaquin River and French Camp Slough each have a "MeHg Concentration Used to Calculate Allocation" set at 0.05 ng/l to reserve assimilative capacity for discharges within the San Joaquin subarea, and have annual average loads of 356 and 11 g/yr, percent reductions of 31% and 35%, and allocated loads of 110 ng/l and 3.9 ng/l, respectively. A load of 2.2 g/yr was reserved for new municipal WWTP discharges expected to service predicted population growth, which was based on a methylmercury concentration of 0.06 ng/l and discharge volume equal to 60% of existing WWTP discharges in the subarea (see Table 8.3).*

The percent allocations were applied to every point source discharge methylmercury concentration and load – except those with pre-determined allocations – within each subarea to calculate corresponding wasteload allocations using Equations 8.4 and 8.5. Methylmercury inputs from agricultural lands, wetlands, and open-water habitat are based on methylmercury loads produced *in situ* and therefore do not have corresponding concentrations. As a result, the percent allocations were applied to such nonpoint source loads within each subarea to calculate corresponding load allocations using only Equation 8.5.

Equation 8.4:
(using City of Stockton WWTP in the San Joaquin subarea as an example)

MeHg Concentration Used to Calculate Allocation (ng/l) =

= % Allocation * Existing average annual effluent MeHg conc.
= 25% * 0.94 ng/l
= 0.24 ng/l

Equation 8.5:

MeHg Wasteload Allocation (g/yr) =

= % Allocation * Existing average annual effluent MeHg load
= 25% * 36 g/yr
= 9.0 g/yr

Sometimes Equation 8.4 resulted in an average methylmercury concentration less than 0.06 ng/l. The preferred allocation strategy described in the draft Basin Plan Amendment staff report entails that no discharger (e.g., WWTPs and MS4s) be required to reduce its discharge average methylmercury concentration to less than 0.06 ng/l. If Equation 8.4 resulted in a value less than 0.06 ng/l for a particular point source discharge, the "Concentration Used to Calculate Allocation" was set at 0.06 ng/l and the allocation percent and equivalent load were calculated using the following equations:

Equation 8.6a: *(using the City of Tracy WWTP in the San Joaquin subarea as an example)*

% Allocation = Proposed implementation goal ÷ Existing average annual effluent MeHg Conc.
= 0.06 ng/l ÷ 0.14 ng/l
= 43%

Equation 8.6b:

$$\text{Equivalent MeHg Load} = \text{\% Allocation} * \text{Existing Annual MeHg Load}$$
$$= 43\% * 1.8 \text{ g/yr}$$
$$= 0.77 \text{ g/yr}$$

The ultimate purpose of this iterative set of calculations is to ensure that the sum of all methylmercury inputs to each Delta subarea does not exceed the assimilative capacity so that the proposed implementation goal for ambient water and proposed fish tissue mercury targets can be achieved in each subarea.

“Existing annual MeHg loads" for MS4 discharges and nonpoint sources in Table 8.4 represent the loads estimated for WY2000-2003, a relatively dry period. Loads discharged by these sources are expected to fluctuate with rainfall and river flow conditions and other environmental factors. Load estimates will be re-evaluated in subsequent phases of the TMDL implementation program as more data become available. As described in Chapter 4 of the draft Basin Plan Amendment staff report, staff recommends that responsible parties for point and nonpoint methylmercury discharges conduct collaborative source characterization and control studies during the next six or so years. To the extent that the efforts to develop methylmercury controls are effective, and/or further scientific information has been collected, the Central Valley Water Board may consider amendments to the Basin Plan to update the methylmercury allocations and implementation plan after the studies are completed.

More than 30% of the methylmercury in the Delta/Yolo Bypass is produced locally in sediment (Table 6.2). Methylmercury production is a positive linear function of the inorganic mercury content of sediment (Chapter 3). This TMDL requires a 110-kg/yr reduction in total mercury from upstream watersheds with mercury sediment concentrations greater than 0.2 mg/kg and large mercury loads (next section). This represents about a 31% decrease in the 20-year average annual loading from the Sacramento Basin (Table 7.1) and should eventually result in a similar proportional decrease in sediment mercury concentrations. Inorganic mercury load reductions elsewhere have resulted in decreases in fish tissue methylmercury concentrations (Table 3.1). It is expected that similar reductions in fish tissue concentration also will occur in the Delta once the mercury content of its sediment decreases. Proposed total mercury load reductions are described in Section 8.2, after Tables 8.4a through 8.4g.

Table 8.4a: Allocations for Methylmercury Sources to the Central Delta Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA* [a]	37	100%	*NA*	37
Atmospheric Deposition			*NA*	7.3	100%	*NA*	7.3
Open Water Habitats			*NA*	370	100%	*NA*	370
Wetland Habitats			*NA*	210	100%	*NA*	210
Tributary Inputs	Bear/Mosher Creeks		0.31	11	100%	0.31	11
	Calaveras River		0.14	26	100%	0.14	26
Urban runoff (nonpoint source)			0.24	0.14	100%	0.24	0.14
WASTELOAD ALLOCATIONS							
NPDES Facilities	Discovery Bay WWTP	CA0078590	0.18	0.37	100%	0.18	0.37
	Lodi White Slough WWTP	CA0079243	0.15	0.93	100%	0.15	0.93
	San Joaquin Co DPW CSA 31-Flag City WWTP	CA0082848	0.08	0.0066	100%	0.08	0.0066
	Unassigned WWTP allocation [b]		*NA*	*NA*	100%	0.06	0.31
NPDES MS4s	Contra Costa (County of)	CAS083313	0.24	0.75	100%	0.24	0.75
	Lodi (City of)	CAS000004	0.24	0.053	100%	0.24	0.053
	Port of Stockton MS4	CAS084077	0.24	0.39	100%	0.24	0.39
	San Joaquin (County of)	CAS000004	0.24	0.57	100%	0.24	0.57
	Stockton Area MS4	CAS083470	0.24	3.6	100%	0.24	3.6
CENTRAL DELTA SUBAREA TOTAL:			**0.060**	**668**	**100%**	**0.060**	**668**

(a) NA: not applicable.

(b) To account for the projected population growth in the Delta region, the Central Delta subarea TMDL contains an unassigned wasteload allocation for new municipal WWTP discharges based on an average methylmercury concentration of 0.06 ng/l and discharge volume equal to 60% of existing WWTP discharges in the subarea (see Table 8.3).

Table 8.4b: Allocations for Methylmercury Sources to the Marsh Creek Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	2.2	17%	*NA*	0.37
Atmospheric Deposition			*NA*	0.23	100%	*NA*	0.23
Open Water Habitats			*NA*	0.18	17%	*NA*	0.031
Wetland Habitats			*NA*	0.34	17%	*NA*	0.058
Tributary Inputs	Marsh Creek		0.25	1.9	18%	0.05	0.34
WASTELOAD ALLOCATIONS							
NPDES Facilities	Brentwood WWTP [(a)]	CA0082660	0.02	0.086	160%	0.02	0.14
	Unassigned WWTP Allocation [(b)]		*NA*	*NA*	100%	0.06	0.16
NPDES MS4s	Contra Costa (County of)	CAS083313	0.24	1.2	25%	0.06	0.30
MARSH CREEK SUBAREA TOTAL:			**0.224**	**6.1**	**27%**	**0.060**	**1.6**

(a) The City of Brentwood WWTP has an existing average effluent methylmercury concentration less than 0.06 ng/l and therefore has a wasteload allocation based on its existing average effluent methylmercury concentration and a discharge volume equal to 160% of its existing volume (See Table 8.3).

(b) To account for the projected population growth in the Delta region, the Marsh Creek subarea TMDL contains an unassigned wasteload allocation for new municipal WWTP discharges based on an average methylmercury concentration of 0.06 ng/l and discharge volume equal to 60% of existing WWTP discharges in the subarea (see Table 8.3).

Table 8.4c: Allocations for Methylmercury Sources to the Mokelumne/Cosumnes Rivers Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	1.6	51%	*NA*	0.82
Atmospheric Deposition			*NA*	0.29	100%	*NA*	0.29
Open Water Habitats			*NA*	4.0	100%	*NA*	4.0
Wetland Habitats			*NA*	30	51%	*NA*	15
Tributary Inputs	Mokelumne River		0.17	110	30%	0.05	33
Urban (nonpoint source)			0.24	0.018	100%	0.24	0.018
WASTELOAD ALLOCATIONS							
NPDES MS4s	San Joaquin (County of)	CAS000004	0.24	0.045	51%	0.12	0.023
MOKELUMNE/COSUMNES RIVERS SUBAREA TOTAL:			**0.166**	**146**	**36%**	**0.060**	**53**

Table 8.4d: Allocations for Methylmercury Sources to the Sacramento River Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	36	56%	*NA*	20
Atmospheric Deposition			*NA*	5.6	100%	*NA*	5.6
Open Water Habitats			*NA*	140	100%	*NA*	140
Wetland Habitats			*NA*	94	56%	*NA*	53
Tributary Inputs	Morrison Creek		0.10	7.5	50%	0.05	3.8
	Sacramento River [(a)]		0.10	2,026	52.35%	0.05	1,061 [(a)]
Urban (nonpoint source)			0.24	0.62	100%	0.24	0.62
WASTELOAD ALLOCATIONS							
NPDES Facilities	Rio Vista WWTP	CA0079588	0.16	0.10	56%	0.09	0.056
	Rio Vista Northwest WWTP [(b)]	CA0083771	*To be determined.* [(b)]				
	Sacramento Combined WWTP [(c)]	CA0079111	0.24	0.43	56%	0.13	0.24
	SRCSD Sacramento River WWTP	CA0077682	0.72	160	56%	0.40	90
	SRCSD Walnut Grove WWTP	CA0078794	2.2	0.24	56%	1.23	0.13
	West Sacramento WWTP [(d)]	CA0079171	0.05	0.39	160%	0.05	0.62
	Unassigned WWTP Allocation [(e)]		*NA*	*NA*	100%	0.06	8.4
NPDES MS4s	Rio Vista (City of)	CAS000004	0.24	0.014	56%	0.13	0.0078
	Sacramento Area MS4	CAS082597	0.24	1.8	56%	0.13	1.0
	San Joaquin (County of)	CAS000004	0.24	0.19	56%	0.13	0.11
	Solano (County of)	CAS000004	0.24	0.073	56%	0.13	0.041
	West Sacramento (City of)	CAS000004	0.24	0.65	56%	0.13	0.36
	Yolo (County of)	CAS000004	0.24	0.073	56%	0.13	0.041
SACRAMENTO RIVER SUBAREA TOTAL:			**0.108**	**2,474**	**56%**	**0.060**	**1,385**

(a) Because of its magnitude, the Sacramento River's existing methylmercury load and percent allocation were not rounded to two significant figures before calculating the allocations for point and nonpoint sources in the Sacramento River subarea. Staff recommends that for compliance purposes the Sacramento River's percent allocation and resulting load allocation be rounded to 50% and 1,000 g/yr, respectively.

(b) A methylmercury allocation for the City of Rio Vista's Northwest WWTP (which began discharging after WY2000-2003) will be determined once it completes one year of monthly monitoring of methylmercury in its discharge. If its annual average effluent methylmercury concentration is less than 0.06 ng/l, it will have a methylmercury wasteload allocation equal to its annual average effluent methylmercury concentration multiplied by its maximum rated discharge volume. If its annual average effluent methylmercury concentration is greater than 0.06 ng/l, it will have a methylmercury wasteload allocation based on a concentration reduction of 44%. If such a reduction would result in an average discharge methylmercury concentration less than 0.06 ng/l, it will have a wasteload allocation based on a methylmercury concentration of 0.06 ng/l. Its wasteload allocation is a component of the "Unassigned WWTP Allocation".

(c) The methylmercury wasteload allocation for the Sacramento Combined WWTP (CA0079111) WWTP is based on the average methylmercury concentration observed in wet weather urban runoff (0.24 ng/l) and the WWTP's average annual discharge volume (464 million gallons per year / 1.3 mgd). The allocation will be re-evaluated after the Sacramento Combined WWTP conducts one year of discharge methylmercury monitoring.

(d) The City of West Sacramento WWTP has an existing average effluent methylmercury concentration less than 0.06 ng/l and therefore has a wasteload allocation based on its existing average effluent methylmercury concentration and a discharge volume equal to 160% of its existing volume (See Table 8.3).

(e) To account for the projected population growth in the Delta region, the Sacramento River subarea TMDL contains an unassigned wasteload allocation for new municipal WWTP discharges based on an average methylmercury concentration of 0.06 ng/l and discharge volume equal to 60% of existing WWTP discharges in the subarea (see Table 8.3).

Table 8.4e: Allocations for Methylmercury Sources to the San Joaquin River Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	23	25%	*NA*	5.8
Atmospheric Deposition			*NA*	2.7	100%	*NA*	2.7
Open Water Habitats			*NA*	48	100%	*NA*	48
Wetland Habitats			*NA*	43	25%	*NA*	11
Tributary Inputs	French Camp Slough		0.14	11	36%	0.05	4.0
	San Joaquin River [(a)]		0.16	356	31%	0.05	110
Urban (nonpoint source)			0.24	0.0022	100%	0.24	0.0022
WASTELOAD ALLOCATIONS							
NPDES Facilities	Deuel Vocational Institute WWTP (b)	CA0078093	0.02	0.013	160%	0.02	0.021
	Manteca WWTP [(c)]	CA0081558	0.22	1.4	27%	0.06	0.38
	Oakwood Lake Subdivision Mining Reclamation [(b)]	CA0082783	0.03	0.38	100%	0.03	0.38
	Stockton WWTP	CA0079138	0.94	36	25%	0.24	9.0
	Tracy WWTP [(c)]	CA0079154	0.14	1.8	43%	0.06	0.77
	Unassigned WWTP Allocation [(d)]		*NA*	*NA*	100%	0.06	2.2
NPDES MS4s	Lathrop (City of)	CAS000004	0.24	0.27	25%	0.06	0.068
	Port of Stockton MS4	CAS084077	0.24	0.010	25%	0.06	0.0025
	San Joaquin (County of)	CAS000004	0.24	2.2	25%	0.06	0.55
	Stockton Area MS4	CAS083470	0.24	0.50	25%	0.06	0.13
	Tracy (City of)	CAS000004	0.24	1.8	25%	0.06	0.45
SAN JOAQUIN RIVER SUBAREA TOTAL:			**0.160**	**528**	**37%**	**0.060**	**195**

(a) Because of its magnitude, the San Joaquin River's existing methylmercury load was not rounded to two significant figures before calculating the allocations for point and nonpoint sources in the San Joaquin River subarea. Coincidently, the San Joaquin River's resulting load allocation was 110 g/yr, which does not require rounding to have two significant digits.

(b) The Deuel Vocational Institute WWTP and Oakwood Lake Subdivision Mining Reclamation discharges have existing average effluent methylmercury concentrations less than 0.06 ng/l. Therefore, the Deuel Vocational Institute WWTP wasteload allocation is based on its existing average effluent methylmercury concentration and a discharge volume equal to 160% of its existing volume (See Table 8.3). The Oakwood Lake Subdivision Mining Reclamation wasteload allocation is based on its existing average effluent methylmercury concentration and average discharge volume. Its discharge is from flood-control pumping from Oakwood Lake, a former excavation pit filled primarily by groundwater, to the San Joaquin River. Discharge volumes and associated methylmercury loads are expected to fluctuate between wet and dry years.

(c) The first iteration of the "percent allocation" calculations resulted in "MeHg Concentration Used to Calculate Allocation" less than 0.06 ng/l for the Manteca and Tracy WWTPs. Therefore, the Manteca and Tracy WWTPs wasteload allocations are based on methylmercury concentrations of 0.06 ng/l, which correspond to percent allocations of 27% and 43%, respectively.

(d) To account for the projected population growth in the Delta region, the San Joaquin River subarea TMDL contains an unassigned wasteload allocation for new municipal WWTP discharges based on an average methylmercury concentration of 0.06 ng/l and discharge volume equal to 60% of existing WWTP discharges in the subarea (see Table 8.3).

Table 8.4f: Allocations for Methylmercury Sources to the West Delta Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	4.1	100%	*NA*	4.1
Atmospheric Deposition			*NA*	2.4	100%	*NA*	2.4
Open Water Habitats			*NA*	190	100%	*NA*	190
Wetland Habitats			*NA*	130	100%	*NA*	130
Urban (nonpoint source)			0.24	0.066	100%	0.24	0.066
WASTELOAD ALLOCATIONS							
NPDES Facilities	GWF Power Systems [(a)]	CA0082309	0.03	0.0019	100%	0.03	0.0052
	Unassigned WWTP Allocation [(b)]		*NA*	*NA*	100%	0.06	0.57
NPDES MS4s	Contra Costa (County of)	CAS083313	0.24	3.2	100%	0.24	3.2
WEST DELTA SUBAREA TOTAL:			**0.083 (a)**	**330**	**100%**	**0.060**	**330**

(a) GWF Power Systems (CA0082309), in the West Delta subarea, acquires its intake water from sources other than ambient surface water and therefore was incorporated in the allocation calculations. GWF effluent methylmercury concentrations are less than the analytical method detection limit (0.03 ng/l; see Table 6.5 in Chapter 6). As a result, staff recommends that its allocation be equal to an annual load of 0.0052 g/yr, calculated by using the methylmercury method detection limit (0.03 ng/l) and its design flow (0.125 mgd) to accommodate expected growth.

(b) To account for projected population growth in the Delta region, the West Delta subarea TMDL contains an unassigned wasteload allocation for new municipal WWTP discharges. There are no WWTPs currently in the West Delta subarea. However, as noted in Table 8.3a, the Ironhouse Sanitary District WWTP is expected to begin discharging to the San Joaquin River sometime in 2009 with a permitted maximum discharge of 4.3 mgd. To account for the Ironhouse discharge and any population growth in the West Delta subarea, staff based the unassigned wasteload allocation (0.57 g/yr) on the “Effluent Volume Predicted to Be Discharged by New WWTPs” for the West Delta subarea (6.9 mgd) and an average methylmercury concentration of 0.06 ng/l. The additional 0.57 g/yr loading should not cause an exceedance of the proposed fish tissue objectives in the West Delta subarea because (1) it is based on the methylmercury goal for ambient water (0.06 ng/l), which includes a 10% margin of safety, and (2) West Delta fish tissue and ambient water methylmercury levels are expected to decrease when actions are implemented to reduce water methylmercury levels in the Sacramento River and Yolo Bypass subareas (e.g., by 44 to 80%), inflows which dominate the West Delta subarea.

Table 8.4g: Allocations for Methylmercury Sources to the Yolo Bypass Subarea

MeHg Source	Tributary or Permittee	Permit #	Existing Average Annual MeHg Conc. (ng/l)	Existing Average Annual MeHg Load (g/yr)	Percent Allocation	MeHg Conc. Used to Calculate Allocation (ng/l)	MeHg Load/ Wasteload Allocation (g/yr)
LOAD ALLOCATIONS							
Agricultural Drainage			*NA*	19	15%	*NA*	2.9
Atmospheric Deposition			*NA*	4.2	100%	*NA*	4.2
Open Water Habitats			*NA*	100	15%	*NA*	15
Wetland Habitats			*NA*	480	15%	*NA*	72
Tributary Inputs	Cache Creek Settling Basin Outflow		0.50	140	10%	0.05	14
	Dixon Area		0.24	3.6	21%	0.05	0.76
	Fremont Weir		0.10	180	50%	0.05	90
	Knights Landing Ridge Cut		0.19	100	26%	0.05	26
	Putah Creek		0.18	11	28%	0.05	3.1
	Ulatis Creek		0.24	9.5	21%	0.05	2.0
	Willow Slough		0.24	18	21%	0.05	3.8
WASTELOAD ALLOCATIONS							
NPDES Facilities	Davis WWTP [(a)]	CA0079049	0.61	0.78	15%	0.09	0.12
	Woodland WWTP [(b)]	CA0077950	0.03	0.25	160%	0.03	0.40
	Unassigned WWTP Allocation [(c)]		*NA*	*NA*	100%	0.06	0.42
NPDES MS4s	Solano (County of)	CAS000004	0.24	0.085	25%	0.06	0.021
	West Sacramento (City of)	CAS000004	0.24	1.1	25%	0.06	0.28
	Yolo (County of)	CAS000004	0.24	0.33	25%	0.06	0.083
YOLO BYPASS [North & South] SUBAREA TOTAL:			**0.273**	**1,069**	**22%**	**0.060**	**235**

(a) The City of Davis WWTP (CA0079049) has two discharge locations; wastewater is discharged from Discharge 001 to the Willow Slough Bypass upstream of the Yolo Bypass and from Discharge 002 to the Conaway Ranch Toe Drain in the Yolo Bypass. The methylmercury load allocation listed in this table applies only to Discharge 002, which discharges seasonally from about February to June. Discharge 001 is encompassed by the Willow Slough watershed methylmercury allocation.

(b) The City of Woodland WWTP has an existing average effluent methylmercury concentration less than 0.06 ng/l and therefore has a wasteload allocation based on its existing average effluent methylmercury concentration and a discharge volume equal to 160% of its existing volume (See Table 8.3).

(c) To account for the projected population growth in the Delta region, the Yolo Bypass subarea TMDL contains an unassigned wasteload allocation for new municipal WWTP discharges based on an average methylmercury concentration of 0.06 ng/l and discharge volume equal to 60% of existing WWTP discharges in the subarea (see Table 8.3).

8.2 Total Mercury Load Limits for Tributary Watersheds

Staff recommends that total mercury limits be implemented in addition to the methylmercury allocations for three reasons: (1) to maintain compliance with the USEPA's criterion of 50 ng/l for total mercury in the water column; (2) to prevent increases in total mercury discharges from causing increases in aqueous and fish methylmercury in the Delta, thereby worsening the impairment; and (3) to meet the San Francisco Bay TMDL allocation to the Central Valley. The TMDL for San Francisco Bay assigned the Central Valley a five-year average total mercury load allocation of 330 kg/yr or a decrease of 110 kg/yr (Section 2.4.2.3).

The total mercury source analysis described in Chapter 7 indicates that almost all the total mercury loading to the Delta and Yolo Bypass comes from tributary inputs. As described in Chapter 4 of the draft Basin Plan Amendment staff report, staff recommends that total mercury load limits be applied to the tributary inputs (which are comprised almost entirely of nonpoint sources) and total mercury concentration limits and pollution prevention measures be implemented by point sources that are likely to increase due to population growth. This section of the TMDL report reviews how the total mercury load limits were calculated for key tributary watersheds.

A reduction of 110 kg/yr represents about a 28% decrease in the 20-year average annual loading[48] from Delta tributaries (Table 7.1). As described in Chapter 4 of the draft Basin Plan Amendment staff report, staff recommends that the 110 kg total mercury reduction be met by reductions in total mercury entering the Delta from the Sacramento Basin. Reduction efforts should focus in the Cache Creek, Feather River, American River, and Putah Creek watersheds (Table 8.5) because these watersheds export the largest volume of highly contaminated sediment (see Tables 7.5 and 7.17 in Chapter 7). Staff recommends that the proposed total mercury reductions for the Sacramento Basin tributaries be based on WY1984-2003 average annual loads. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. The proposed reductions will enable Delta waters to maintain compliance with the CTR criterion of 50 ng/l (Section 7.4 in Chapter 7).

The Cache Creek Settling Basin (CCSB) is a 3,600-acre structure located at the base of the Cache Creek watershed. The U.S. Army Corp of Engineers initially constructed the CCSB in 1937 to contain sediment and maintain the flood capacity of the Yolo Bypass. The CCSB was modified in 1993 to increase its sediment trapping efficiency. However, no provision was made for removing the additional trapped material. Most of the mercury in Cache Creek is transported on sediment. Therefore, an increase in sediment trapping also results in deposition and retention of mercury. The CCSB currently traps about half of the sediment and mercury transported by Cache Creek (Foe and Croyle, 1998; CDM, 2004; Cooke *et al.*, 2004; CDM, 2004; Appendices F and I). The rest is exported to the Delta through the Yolo Bypass. Currently, the CCSB receives about 224 kg/yr from the Cache Creek watershed and discharges about 118 kg/yr to the Yolo Bypass. The sediment/mercury trapping efficiency of the CCSB is expected to decrease as it fills and may reach zero in about 35 years unless a maintenance

[48] Year-to-year loads are expected to fluctuate with water volume and other environmental factors.

program is instituted to periodically remove material (CDM, 2004). A non-operational CCSB would result in a mercury discharge to the Yolo Bypass and Delta of about 224 kg/yr, an addition of 106 kg/yr mercury loading (Table 7.6b).

Two sets of actions are considered in the draft Basin Plan Amendment staff report (Chapter 4 and Appendix C) for the Cache Creek Settling Basin that would reduce mercury discharges to the Yolo Bypass and Delta. First, mercury loads entering the CCSB from the Cache Creek watershed could be reduced. The Basin Plan Amendment for control of mercury in Cache Creek was adopted by the Central Valley Water Board in October 2005. Implementation actions described in the Basin Plan Amendment report would reduce mercury loads *entering* the Cache Creek Settling Basin by about 60 kg/year (Cooke and Morris, 2005), from a 20-year average of 224 kg/yr to 164 kg/yr. Given a modeled basin trapping efficiency of about 64% (CDM, 2004, Table 4-3), the watershed implementation actions would reduce basin total mercury mass discharges to the Yolo Bypass by 32 kg/yr. Approximately 25 kg of the 60 kg/year reduction in the Cache Creek watershed may come from instituting control programs at all major mercury mines in the watershed.[49] The remainder of the reduction will be achieved by control of erosion in mercury-enriched areas and by remediation/removal of contaminated floodplain sediment in the Cache Creek canyon and in Bear Creek. However, most the total mercury load now leaving the CCSB appears to originate from erosion of mercury contaminated sediment in the active flood plain downstream of the mines. Studies are required by the Cache Creek mercury control program to evaluate in-stream sediment control options. It is unclear whether environmentally acceptable, cost effective control programs can be developed to significantly curtail the movement of this material.

As result, a second set of actions could focus on decreasing the mercury load leaving the Cache Creek Settling Basin. A program should be instituted to (a) periodically excavate the material presently accumulating in the CCSB, and (b) make additional modifications to the CCSB to increase trapping efficiency. Initial modeling results indicate that CCSB operation and design could be modified to improve the sediment and mercury mass trapping efficiency of the CCSB from 64% to 75% (CDM, 2004, Table 4-3, Alternative 5 - Excavate and Raise Weir Early). Decreasing mercury inputs to the CCSB to 164 kg/yr through the watershed control program and increasing the trapping efficiency of the CCSB to 75% results in an export to the Yolo Bypass of 41 kg/yr, which represents a decrease of 77 kg/yr from current loading. This reduction is approximately 70% of the 110-kg/yr reduction required by the San Francisco Bay mercury TMDL.

The remaining 33 kg/yr reduction required to achieve a 110 kg/yr reduction in Central Valley total mercury loading to San Francisco Bay is assigned to the sum of the mercury loads leaving the Feather River, American River and Putah Creek watersheds (90 kg/yr, Table 8.5). This equates to a reduction of 37% and an acceptable load of 57 kg/yr leaving these three watersheds. Monitoring is underway to identify sources of methyl and total mercury in these and the other Sacramento Basin tributary watersheds. Specific limits for the Feather River, American River and Putah Creek watersheds are not defined in Table 8.5 to allow for greater flexibility in developing future implementation strategies. However, the sum of the load reductions for these watersheds and Cache Creek Settling Basin outflow must equal 110 kg/yr.

[49] The mines are located in Harley Gulch, Sulfur and Bear Creeks and Clear Lake.

Each of these watersheds contains waterways already identified on the CWA Section 303(d) List as impaired by mercury. Hence, each will be the focus of future watershed-specific TMDL programs. Specific load reductions for each watershed will be specified in its TMDL report.

A 110 kg reduction in total mercury from the Sacramento Basin is a reasonable goal for the first phase of the Delta mercury control program. For example, Feather River and Cache Creek Settling Basin outflows have average methylmercury concentrations of 0.10 and 0.50 ng/l, respectively (see Appendix F for a summary of available methylmercury concentration data provided in Appendix L). If Feather River and Cache Creek watershed outflow methylmercury concentrations need to be reduced to 0.05 ng/l to enable compliance with the methylmercury allocations for Fremont Weir and Cache Creek Settling Basin discharges, they would require reductions of 50% and 90%, respectively. If the proposed source characterization and control studies find no means to reduce aqueous methylmercury by methods other than total mercury reduction, than the total mercury exports from the Feather River (67 kg/yr) and CCSB (118 kg) may require reductions of a similar magnitude. A 50% reduction of Feather River watershed total mercury outflows is about 34 kg/yr, and an 90% reduction of CCSB exports is about 106 kg/yr, totaling about 140 kg/yr.

Table 8.5: Total Mercury Load Limits for Key Sacramento Basin Tributaries

Tributary	Existing Annual TotHg Load [(a)] (kg/yr)	Required Reduction (kg/yr)	Acceptable TotHg Load (kg/yr)
Cache Creek Settling Basin Outflow	118	77	41
American River	14		
Feather River	67	33	57
Putah Creek	8.8		
TOTAL:	**208**	**110**	**98**

(a) Existing annual TotHg loads represent the average annual loads estimated for WY1984-2003. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. Annual loads are expected to fluctuate with water volume and other factors.

8.3 Margin of Safety

Implicit and explicit margins of safety are included in the aqueous methylmercury goal for the Delta. In addition, while not a direct margin of safety, the implementation plan (Chapter 4 in the draft Basin Plan Amendment staff report) calls for updated fish advisories in the Delta and an expanded outreach program to educate humans fishing in the Delta.

The proposed aqueous methylmercury goal of 0.06 ng/l (Chapter 5) incorporates an explicit margin of safety of approximately 10%. The linkage analysis (Section 5.2) predicted a safe level of 0.066 ng/l for average aqueous methylmercury, from which 0.006 was subtracted to provide a margin of safety.

In addition, there is an implicit margin of safety for wildlife species that consume Delta fish. As outlined in the previous paragraph, the aqueous methylmercury goal corresponds to 0.24 mg/kg mercury in large TL4 fish, which was calculated for the protection of humans consuming about one meal per week. As shown in Table 4.9 (Chapter 4), the wildlife targets for smaller and lower trophic level fish correspond to large TL4 fish mercury levels that range from 0.30 mg/kg (for Western grebe) to 1.12 mg/kg (for Western snowy plover). These values correspond to 350-mm largemouth bass mercury levels of 0.31 and 1.34 mg/kg. When entered into the regression equation for largemouth bass and unfiltered average aqueous methylmercury (Figure 5.2[A]), these values translate to aqueous methylmercury concentrations of 0.08 ng/l and 0.19 ng/l, allowing a margin of safety of 25% or more, depending on the wildlife species.

8.4 Seasonal & Inter-annual Variability

8.4.1 Variability in Aqueous Methyl and Total Mercury

Mercury loads in Delta tributary inputs fluctuate because of seasonal and inter-annual variation. Winter precipitation increases the sediment and total mercury loads entering the Delta through erosion and re-suspension of sediment. Most of the total mercury coming from tributaries and direct surface runoff enters the Delta during high flow events. In contrast, methylmercury production is typically higher during the summer months. In addition, greater mercury loads enter the Delta during wet water years.

Seasonal and inter-annual variability in methylmercury loads were accounted for in the source analysis and methylmercury load allocations by evaluating annual average loads for Delta sources and losses for WY2000 to 2003, a relatively dry period that encompasses the available concentration data for the major Delta inputs and exports. Twenty-year average, annual loads of total mercury were estimated for tributary loads based on flow and precipitation records for WY1984-2003. This 20-year period includes a mix of wet and dry years that is statistically similar to what has occurred in the Sacramento Basin over the last 100 years. However, insufficient data were available to estimate 20-year average annual loads for methylmercury sources. Methylmercury allocations and total mercury limits will be re-evaluated as additional information becomes available. Future monitoring programs will accommodate long-term inter-annual variability by evaluating whether sources are meeting allocations on a multi-year basis.

8.4.2 Variability in Biota Mercury

Seasonal and inter-annual variation also occurs in biota. Slotton and others (2003) found that Delta species exhibited both seasonal and inter-annual variability in mercury body burden. Corbicula (clams) had higher mercury concentrations in the spring while inland silversides (representative forage fish species) were higher in fall. In addition, silverside bioaccumulation was greater in 1998 than in 1999 and 2000 at many locations in the Delta. Davis and others (2002) measured higher mercury concentrations in similar sized largemouth bass in 1999 than in 2000. The researchers noted that the winter of 1997 was very wet and speculated that the high flows may have introduced significant quantities of "new" mercury that was methylated and incorporated into forage fish in 1998. Predacious fish like largemouth bass, which feed upon silversides, took an additional year to reflect the higher methylmercury concentrations.

Seasonal and inter-annual variability in large fish was accounted for in the numeric targets and linkage analysis by using data collected over multiple years. Future monitoring will accommodate seasonal and inter-annual variability by sampling large fish about every ten years.

8.4.3 Regional and Global Change

Several ongoing regional and global changes may affect methyl and total mercury loading in the Delta. This section identifies several of these.

8.4.3.1 Population Growth

The Delta and its tributary watersheds are experiencing substantial population growth. Population in the Central Valley increased by about 20% between 1990 and 2000 (AFT, 2006; CDOF, 2004). This resulted in the conversion of about 98,000 acres of agricultural land to urban uses (AFT, 2006). Four of the five fastest growing cities in the Sacramento Valley are located within about one day's travel time (about 20 to 30 miles by water) of the Delta. The California Department of Finance predicts that populations in the Delta/Yolo Bypass counties[50] will increase 76% to 213% by 2050 (CDOF, 2007), with an average increase of about 120%.

Increasing populations will result in increased discharges from municipal wastewater treatment plants. In addition, urbanization increases both volume and discharge velocity of runoff because of the increase in impervious surfaces. Urbanization also tends to increase pollutant loading because impervious surfaces neither absorb water nor remove pollutants, and urban development tends to create new anthropogenic mercury pollution sources. As Chapters 6 and 7 indicate, urban runoff in the Sacramento, Stockton and Tracy areas has higher methylmercury and total mercury concentrations than ambient river concentrations. However, little is known about how the conversion of agricultural land to urban uses affects methylmercury concentration.

MS4 allocations apply to all urban acreage within MS4 service areas within each Delta subarea and apply to the sum of methylmercury loads in existing urban acreage runoff and in runoff from future urbanized lands within the MS4 service areas. Staff assumed that, in general, NPDES-permitted municipal WWTP discharges throughout the Delta/Yolo Bypass would increase by 120%. Staff assumed that half of that growth will be addressed by expansions to existing facilities in each Delta subarea, and that half will be serviced by new facilities in each subarea. As described in Section 8.1.2 and shown in Tables 8.3 and 8.4, the allocation strategy incorporates the assumption that existing municipal WWTPs will increase their discharge volumes by 60% and reserves assimilative capacity for new WWTP discharges.

Chapter 4 in the draft Basin Plan Amendment staff report reviews possible implementation strategies to address the methylmercury allocations and total mercury limits for municipal WWTP discharges and urban runoff in the Delta region.

---

[50] The CDOF predicts the following population increases by 2050: Contra Costa County - 89%, Sacramento County - 76%, San Joaquin County - 213%, Solano County - 105%, and Yolo County - 93% (CDOF, 2007).

8.4.3.2 Restoration of Wetlands

Research conducted in the Delta and elsewhere has found that wetlands are efficient sites for methylmercury production. There are currently about 26,600 acres of wetlands within the Delta/Yolo Bypass (USFWS, 2006). The Record of Decision for the CALFED Bay-Delta Program commits it to restore 30,000 to 45,000 acres of fresh, emergent tidal wetlands, 17,000 acres of fresh, emergent nontidal wetlands, and 28,000 acres of seasonal wetlands in the Delta by 2030 (CALFED Bay-Delta Program, 2000a). This is a total of 75,000 to 90,000 acres of additional seasonal and permanent wetlands in the Delta, which represents about a three to four times increase in wetland acreage from current conditions. Many of the proposed restoration sites are downstream of mercury-enriched watersheds. Marsh restoration efforts below mercury enriched watersheds are proposed for the following locations: Yolo Bypass downstream of Cache and Putah Creeks; Dutch Flats downstream of the Mount Diablo Mercury mine in the Marsh Creek watershed; and Staten Island and the Cosumnes River Wildlife Refuge near the confluence of the Cosumnes River and Mokelumne River.

Mass balance calculations indicated that methylmercury flux from wetland sediments may account for approximately 983 g/year of methylmercury (see Table 6.2 in Chapter 6), or about 19% of the total methylmercury budget for the Delta. A doubling to tripling in methylmercury loading from wetland sediments could increase overall Delta loading by about 16 to 27%. The linkage relationship suggests that such an increase could result in a 28 to 48% increase in mercury concentrations in standard 350-mm largemouth bass (Figure 5.3). Chapter 4 in the draft Basin Plan Amendment staff report provides a description of staff's suggested Central Valley Water Board policy for new wetland creation.

8.4.3.3 Decreasing Sediment Loads

The sediment load in the Sacramento River decreased by about 50% between 1957 and 2001 (Wright and Schoellhamer, 2004). The decrease is believed to be caused by the trapping of sediment in reservoirs, a decrease in erodible material from hydraulic mining, changes in land use, and construction of levees (Wright and Schoellhamer, 2004; James, 2004). Mercury loads are likely to have also decreased during the same period because much of the inorganic mercury is transported on sediment particles. It is not known what the magnitude of the decrease in mercury loading has been and whether it will continue in the future. The decrease in sediment loading suggests that the relative proportion of erodible material from upstream watersheds may also be changing. The present 20-year volume-weighted average mercury to TSS ratio of sediment entering the Delta is approximately 0.18 mg/kg. This value may change depending on the new sources of sediment. The mercury content of surficial sediment is important, as it is one of the major factors controlling methylmercury production. Methylmercury production in Delta/Yolo Bypass sediment now accounts for about 36% of the methylmercury in the Delta (Figure 6.11). It is not clear how this proportion may change in the future.

8.4.3.4 Climate Change

Recent studies indicate that global warming may disrupt traditional weather and run-off patterns and increase the frequency and severity of summer droughts and springtime flooding (Brekke *et al.*, 2004; Knowles and Cayan, 2002; Miller *et al.*, 2003; Service, 2004; Stewart *et al.*, 2004). Trends over the last 50 years indicate that more precipitation in the Sierra Nevada Mountains is occurring as rain, and that snow is melting earlier in the spring, resulting in a reduced snow pack and less water in reservoirs in the summer and fall. Climate models suggest that these trends may become more pronounced with continued warming. The net result may have unpredictable consequences on ecological processes in the Delta including the synthesis and bioaccumulation of methylmercury. The source analyses, linkage analysis, methylmercury allocations and total mercury limits described in this TMDL are based on present climate conditions. Staff will re-evaluate linkage relationships associated with changing environmental conditions as more information becomes available in the future.

Key points and options to consider are summarized on the following two pages.

Key Points

- Methylmercury allocations are divided among “wasteload allocations” for point sources and “load allocations” for nonpoint sources. The TMDL is the sum of these components. The allocation strategy used in this chapter is based on staff’s recommended strategy described in Chapter 4 of the draft Basin Plan Amendment staff report and is designed to remedy the beneficial use impairment in all subareas of the Delta. Total mercury limits were developed to maintain compliance with the USEPA’s CTR for total mercury in the water column and to achieve the San Francisco Bay mercury control program’s total mercury allocation for the Central Valley, as well as to help enable methylmercury reductions in Delta water and fish.

Methylmercury:

- Methylmercury allocations were made in terms of the existing assimilative capacity of the different Delta subareas. The recommended goal for ambient water is an average annual concentration of 0.06 ng/l methylmercury in unfiltered water (Chapter 5). This goal describes the assimilative capacity of Delta waters in terms of concentration and encompasses a margin of safety of approximately 10%. Central Valley Water Board staff anticipates that as the average concentration of methylmercury in each Delta subarea decreases to the aqueous goal, the targets for fish tissue will be attained.
- To determine necessary reductions, the existing average aqueous methylmercury levels in ambient water in the Delta subareas were compared to the methylmercury goal. The amount of reduction needed in each subarea is expressed as a percent of the existing concentration. Percent reductions required to meet the goal ranged from 0% in the Central Delta subarea to more than 70% in the Yolo Bypass and Mokelumne River subareas.
- Central Valley Water Board staff recommends that sources with existing or allocated average methylmercury concentrations at or below 0.06 ng/l be considered dilution and assigned wasteload allocations that entail no net increase in methylmercury concentration.

Total Mercury:

- Central Valley Water Board staff recommends that the 110 kg total mercury reduction allocated by the San Francisco Bay mercury control program to the Central Valley be met by reductions in total mercury entering the Delta from the Cache Creek, Feather River, American River and Putah Creek watersheds in the Sacramento Basin. These watersheds have both relatively large mercury loadings and high mercury to TSS ratios, which makes them likely candidates for load reduction programs. Additional reductions may be recommended in future phases of the Delta mercury implementation program to meet the proposed methylmercury goal for ambient Delta waters.

Options to Consider

- The methylmercury allocations described in this chapter reflect the preferred implementation alternative described in Chapter 4 of the draft Basin Plan Amendment staff report and are designed to address the beneficial use impairment in all subareas of the Delta. However, as described in the draft Basin Plan Amendment staff report, a number of alternatives are possible. The Central Valley Water Board will consider a variety of allocation strategies and implementation alternatives as part of the Basin Plan amendment process.
- Likewise, a variety of total mercury reduction strategies are possible. A total mercury load reduction strategy was developed to comply with the San Francisco Bay mercury TMDL allocation for to the Central Valley and the USEPA's criterion for human health protection, and to help enable methylmercury reductions in Delta water and fish. Staff applied the San Francisco Bay TMDL's allocated reduction of 110 kg total mercury reduction to loads from the Cache Creek, Feather River, American River and Putah Creek watersheds because these watersheds export the largest volume of highly contaminated sediment while within-Delta sources comprise only a couple percent of total mercury inputs. Chapter 4 of the draft BPA staff report describes additional strategies for minimizing increases from total mercury sources that may increase as a result of population growth and regional water management changes.

9 REFERENCES

AFT. 2006. The Future is Now: Central Valley Farmland at the Tipping Point? American Farmland Trust (AFT). Available at: http://www.farmland.org/programs/states/futureisnow/default.asp. Accessed: 24 September 2006.

Alpers, C.N., R.C. Antweiler, H.E. Taylor, P.D. Dileanis, and J.L. Domagalski. 2000. *Metals Transport in the Sacramento River, California, 1996-1997, Volume 1: Methods and Data.* U.S. Geological Survey Water-Resources Investigation Report 99-4286. Sacramento, CA.

Armstrong F. and D. Scott. 1979. Decrease in mercury content of fishes in Ball Lake, Ontario, since imposition of controls on mercury discharge. *Journal of the Fish Research Board of Canada*, 36: 670-672.

ARB. 2003. Data retrieved from the California Emission Inventory Development and Reporting System (CEIDARS), database year 2002. California Air Resources Board (ARB), Emission Inventory Branch, Sacramento, CA.

Ayers, R.S. and D.W. Westcot. 1985. *Water Quality for Agriculture*. Rome, Food and Agriculture Organization of the United Nations. Irrigation Drainage Paper No. 29, Rev. 1.

Beard, R.R. 1987. *Treating Gold Ores by Amalgamation*. Arizona Department of Mines and Mineral Resources Circular No. 27, March 1987. Text of a presentation given at an Ehrenberg Arizona Miner's Seminar. Available at: http://www.admmr.state.az.us/Publications/circ027amalgam.html

Becker, D.S. and G.N. Bigham. 1995. Distribution of mercury in the aquatic food web of Onondaga Lake, New York. *Water, Air, and Soil Pollution,* 80: 563-571.

Benoit, J.M., C.C. Gilmour, A. Heyes, R.P. Mason and C. L. Miller. 2003. Geochemical and biological controls over methylmercury production and degradation in aquatic ecosystems. *In*: *Biogeochemistry of Environmentally Important Trace Elements*, ACS Symposium Series #835. Y. Chai and O.C. Braids (editors). Washington, D.C.: American Chemical Society, pp.262-297.

Benoit, J.M., C.C. Gilmour, and R. Mason. 2001. The influence of sulfide on solid-phase mercury bioavailability for methylation by pure cultures of Desulfobulbus propionicus (Ipr3). *Environmental Science & Technology*, 35: 127-132.

Benoit, J.M., C.C. Gilmour, R. Mason, A. Heyes. 1999. Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment and pore waters. *Environmental Science & Technology*, 33: 951-957.

Benoit, J.M., C.C. Gilmour, R.P. Mason, G.S. Riedel, and G.F. Riedel. 1998. Behavior of mercury in the Patuxent River Estuary. *Biogeochemistry*, 40: 249-265.

Benoit, J.M., R.P. Mason, and C.C. Gilmour. 1999. Estimation of mercury-sulfide speciation and bioavailability in sediment pore waters using octanol-water partitioning and implications for availability to methylating bacteria. *Environmental Toxicology and Chemistry*, 18(10): 2138-2141.

Bloom, N.S. 2003. *Solid Phase Mercury Speciation and Incubation Studies in or Related to Mine-site Runoff in the Cache Creek Watershed (CA)*. Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human

Health Impacts of Mercury in the Bay-Delta Watershed (Task 7C). Frontier Geosciences Inc. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Bloom, N.S., G.A. Gill, S. Cappellino, C. Dobbs, L. McShea, C. Driscoll, R. Mason and J. Rudd. 1999. An investigation regarding the speciation and cycling of mercury in Lavaca Bay, Texas, sediments. *Environmental Science & Technology*, 33: 7-13.

Bodaly, R.A., J.W.M. Rudd, and R.J. Flett. 1998. Effect of urban sewage treatment on total and methyl mercury concentrations in effluent. *Biogeochemistry*, 40: 279-291.

Bodaly, R.A., V.L. St. Louis, M.J. Paterson, R.J.P. Fudge, B.D. Hall, D.M. Rosenberg, and J.W.M. Rudd. 1997. Bioaccumulation of mercury in the aquatic food chain in newly flooded areas. In: *Metal Ions in Biological Systems, Vol. 34: Mercury and Its Effects on Environment and Biology*. A. Sigel and H. Sigel (editors). New York: Marcel Dekker, pp. 259-287.

Bosworth, D.H., S.J. Louie, M.L. Wood, D.J. Little, and H. Kulesza. 2008. *A Review of Methylmercury Discharges from NPDES Facilities in California's Central Valley*. California Regional Water Quality Control Board, Central Valley Region, Draft Staff Report. February 2008.

Bradford, G.R., A.C. Chang, A.L. Page, D. Bakhtar1, J.A. Frampton, and H. Wright. 1996. *Background Concentrations of Trace and Major Elements in California Soils*. Kearney Foundation Special Report. Kearney Foundation of Soil Science, Division of Agriculture and Natural Resources, University of California. March 1996. Table 1 A (Series and Location of Benchmark Soils) and Table 2 (Total Concentrations of Elements in Benchmark Soils).

Brekke, L.D., N.L. Miller, K.E. Bashford, N.W.T. Quinn, and J.A. Dracup. 2004. Climate Change Impacts Uncertainty for Water Resources in the San Joaquin River Basin, California. *Journal of the American Water Resources Association*, 40 (1): 149-164.

Brodberg, R. and S. Klasing. 2003. *Evaluation of Potential Health Effects of Eating Fish From Black Butte Reservoir (Glenn and Tehama Counties): Guidelines for Sport Fish Consumption.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Pesticide and Environmental Toxicology Section. Oakland, CA. December 2003. Guidelines for Sport Fish Consumption. Available at: http://www.oehha.ca.gov/fish/pdf/BlackButteDec03final.pdf. Accessed: 19 August 2005.

Brumbaugh, W.G., D.P. Krabbenhoft, D.R. Helsel, J.G. Wiener, and K.R. Echols. 2001. *A National Pilot Study of Mercury Contamination of Aquatic Ecosystems Along Multiple Gradients: Bioaccumulation in Fish*. U.S. Geological Survey Biological Science Report 2001-0009. September 2001.

Byington, A., K. Coale, G. Gill, and K. Choe. 2005. *Photo-degradation of Methyl Mercury (MMHg) in the Sacramento – San Joaquin Delta: A Major Sink.* Poster Presentation, Celebrating Science Stewardship, State of the San Francisco Estuary Conference, 7th Biennial, October 4-6, 2005, Oakland, CA.

CALFED Bay-Delta Program. 2000a. *Ecosystem Restoration Program Plan, Volume II: Ecological Management Zone Visions*. Final Programmatic EIS/EIR Technical Appendix. July 2000. Available at: http://calwater.ca.gov/CALFEDDocuments/Final_EIS_EIR.shtml.

CALFED Bay-Delta Program. 2000b. *Implementation Plan*. Final Programmatic EIS/EIR Technical Appendix. July 2000. Available at: http://calwater.ca.gov/CALFEDDocuments/ Final_EIS_EIR.shtml.

CALFED Bay-Delta Program. 2004a. Storage Program. Multi Year Program Plan (Years 5-8). Available at: http://calwater.ca.gov/programplans_2004/storage_program_Plan_7-04.pdf.

CALFED Bay-Delta Program. 2004b. Conveyance Program. Multi Year Program Plan (Years 5-8). Available at: http://calwater.ca.gov/programplans_2004/conveyance_ program_Plan_7-04.pdf.

Cappiella, K., C. Malzone, R. Smith and B. Jaffe. 2001. *Historical Bathymetric Change in Suisun Bay: 1867-1990.* United States Geological Survey (USGS). Available: http://sfbay.wr.usgs.gov/access/Bathy/suisunbay/. Last revised: October 2001.

CDFG. 2000-2001. *Central Valley Salmon and Steelhead Harvest Monitoring Project.* 1999 and 2000 creel survey data queried from the California Department of Fish and Game (CDFG) creel database.

CDFG. 2002. *California Wildlife Habitat Relationships System Version 8*. California Department of Fish and Game. Available at: http://www.dfg.ca.gov/whdab/html/cwhr.html.

CDFG. 2005. *A List of California Wildlife Species That May Be at Risk from Consumption of Mercury-Contaminated Fish in Mercury-Impaired Waters in the Central Valley Region.* Report by W. Piekarski, M. Puckett, and M. Stephenson, California Department of Fish and Game Moss Landing Marine Laboratories, Moss Landing, CA, prepared for the Central Valley Regional Water Quality Control Board. May 2005.

CDHS. 2004. *Research, Outreach, and Education on Fish Contamination in the Sacramento-San Joaquin Delta and Tributaries (AKA Delta Fish Project) Phase 1 Needs Assessment Final Report.* Prepared by the California Department of Health Services (CDHS), Environmental Health Investigations Branch. Oakland. January 2004.

CDHS, 2005. *Report to the State Water Resources Control Board on Task 3 Fish and Shellfish Tissue Consumption Study.* California Department of Health Services Environmental Health Investigations Branch, Oakland, 29 March.

CDHS. 2006. Fish Mercury Project: *Fishing Activities in the North Delta and Sacramento River Watershed 2006.* California Department of Health Services (CDHS). June. Available at: http://www.sfei.org/cmr/fishmercury/2007_Annual_meeting/Report%20on%20Fishing%20Activity%20in%20the%20North%20Delta%20and%20Sacramento%20River.pdf. Accessed: July 2007.

CDM. 2004. *Cache Creek Settling Basin Mercury Study: Phase 2 - Sediment Transport Modeling*. Technical Memorandum Prepared for the Central Valley Regional Water Quality Control Board in Cooperation with the U.S. Army Corps of Engineers Sacramento District, the State of California Reclamation Board and the California Bay-Delta Authority. July 2004.

CDOF. 2004. State of California, Department of Finance, Population Projections by Race/Ethnicity for California and Its Counties 2000–2050, Sacramento, California, May 2004. Available at: http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Projections/P1/P1.asp. Accessed: 24 September 2006.

Choe, K.Y. 2002. *Biogeochemistry of monomethyl mercury in San Francisco Bay Estuary*. Texas A&M University, Galveston, Ph.D. dissertation, 195 p.

Churchill, R. 2000. *Contributions of mercury to California's environment from mercury and gold mining activities – Insights from the historical record.* Manuscript and slides for oral conference presentation at: Assessing and Managing Mercury from Historic and Current Mining Activities, November 28-30, 2000. Cathedral Hill Hotel, San Francisco, CA. Sponsored by the U.S. Environmental Protection Agency, Office of Research and Development.

City of Sacramento. 1996. *Mercury Monitoring Plan per Provision 5 of the City of Sacramento's Combined Sewer System's NPDES Permit No. CA0079111.* Letter report submitted to the Central Valley Water Board by the City of Sacramento Department of Utilities with review of mercury monitoring results. May 23, 1996.

CMP. 2004. Microsoft Access database of Coordinated Monitoring Program water quality data through August 2003. Database and updates provided by Larry Walker Associates (Mike Trouchon) and Sacramento Regional County Sanitation District (Steve Nebozuk, CMP Program Manager) to Central Valley Regional Water Quality Control Board (Michelle Wood, Environmental Scientist, Sacramento).

Compeau, G. and R. Bartha. 1985. Sulfate-reducing bacteria: Principal methylators of mercury in anoxic estuarine sediment. *Applied Environmental Microbiology*, 50: 498-502.

Conaway, C.H., S. Squire, and R. Mason. 2003. Mercury speciation in the San Francisco Bay Estuary. *Marine Chemistry*, 80: 199-225.

Cooke, J., C. Foe, A. Stanish and P. Morris. 2004. *Cache Creek, Bear Creek, and Harley Gulch TMDL for Mercury.* Central Valley Regional Water Quality Control Board Staff Report. November 2004.

Cooke, J. and P. Morris. 2005. *Amendments to The Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for the Control of Mercury Cache Creek, Bear Creek, and Harley Gulch.* Central Valley Regional Water Quality Control Board, Final Staff Report. Sacramento. October. Available at: http://www.waterboards.ca.gov/centralvalley/programs/tmdl/Cache-SulphurCreek/cache-ck-hg-final-rpt-oct05.pdf

CVRWQCB. 1998. *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board - Central Valley Region.* Fourth Edition. Central Valley Regional Water Quality Control Board (CVRWQCB). Sacramento, CA.

Dansereau, M., N. Lariviere, D. Du Tremblay, and D. Belanger. 1999. Reproductive performance of two generations of female semidomesticated mink fed diets containing organic mercury contaminated freshwater fish. *Archives of Environmental Contamination and Toxicology*, 36: 221-226.

Davis, J.A, B.K. Greenfield, G. Ichikawa and M. Stephenson. 2003. *Mercury in Sport Fish from the Delta Region.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 2A). San Francisco Estuary Institute and Moss Landing Marine Laboratories. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Davis, J.A., M.D. May, G. Ichikawa, and D. Crane. 2000. *Contaminant Concentrations in Fish from the Sacramento-San Joaquin Delta and Lower San Joaquin River – 1998*. San Francisco Estuary Institute report. Richmond, California. September 2000.

Domagalski, J. 2001. Mercury and methylmercury in water and sediment of the Sacramento River Basin, California. *Applied Geochemistry*, 16: 1677-1691.

DPR. 2002. Pesticide Use Report (PUR) Database. Data available for 1990-2001. California Department of Pesticide Regulation (DPR), Sacramento, CA.

DPRec. 1997. *The Delta: Sacramento-San Joaquin Delta Boating and Recreation Survey*. Prepared by the Department of Parks and Recreation for the Delta Protection Commission and the Department of Boating and Waterways. September. Available at: http://www.delta.ca.gov/recreation/survey/default.asp. Accessed: September 2007.

DWR. 1993-2003. Land Use Data. California Department of Water Resources. Available at: http://www.landwateruse.water.ca.gov/basicdata/landuse/digitalsurveys.cfm.

DWR. 1995. *Sacramento – San Joaquin Delta Atlas.* California Department of Water Resources (DWR), Division of Planning and Local Assistance, Office of Water Education, and DWR Photography. Reprinted July 1995.

DWR. 2003. *Sacramento Valley Flood Control System: Estimated Channel Capacity, Reclamation and Levee Districts.* Department of Water Resources (DWR) map of channel capacities and levees maintained by DWR, reclamation, levee, and drainage districts and municipalities. November 2003.

DWR. 2005. *California Water Plan Update 2005, Volume 3 – Regional Reports: Chapter 12. Sacramento-San Joaquin Delta Region*. California Water Plan Update Bulletin 160-05. Public Review Draft, April 2005. Available at: http://www.waterplan.water.ca.gov/. Accessed: 9 June 2005.

DWR. 2006. *Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices.* DWR California Cooperative Snow Surveys. Sacramento, CA. Available at: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST. Accessed: 24 September 2006.

Elert, G. (editor). 2002. *Density of Seawater: The Physics Factbook*. Prepared by E. LaValley, and E. Cartagena. Available at: http://hypertextbook.com/facts/2002/EdwardLaValley.shtml.

Falter, R. and R. Wilken. 1998. Isotopenexperimente zur Ermittlung des abiotischen Quecksilber-Methylierungspotentials eines Rheinsediments. (Isotope experiments for the determination of abiotic mercury methylation potential of a Rhine River sediment.) *Vom Wasser*, 90 (1998): 217-232. Available at: http://www.geographie.uni-freiburg.de/fb/liste.php?sachgruppe=1468

Foe, C.G. 2003. *Mercury Mass Balance for the Freshwater Sacramento-San Joaquin Bay-Delta Estuary*. Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 1A). California Regional Water Quality Control Board, Central Valley Region. Sacramento, CA. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Foe, C.G. 2007. *Review of Paper by Peterson et al. entitled "Mercury Concentrations in Fish from Streams and Rivers Throughout the Western United States".* Memorandum from Chris Foe (Staff Environmental Scientist, Central Valley Water Quality Control Board, Sacramento Office) to Pamela C. Creedon (Executive Officer, Central Valley Water Quality Control Board). 23 May 2007.

Foe, C.G. and W. Croyle. 1998. *Mercury Concentrations and Loads from the Sacramento River and from Cache Creek to the Sacramento-San Joaquin Delta Estuary.* California Regional Water Quality Control Board, Central Valley Region. Sacramento, CA. Staff report. June 1998.

Foe, C.G., S.J. Louie, and D.H. Bosworth. 2007. Methyl Mercury, Total Mercury, and Sediment Concentrations and Loads in the Yolo Bypass During High Flow (Task 2, CALFED Contract ERP-02-C06-A). Poster presentation at the CALFED Bay-Delta Program Annual Workshop and Review of Mercury Projects, Sacramento, April 23-25.

Foe, C.G., M. Stephenson, and A. Stanish. 2002. *Pilot Transplant Studies with the Introduced Asiatic Clam, Corbicula fluminea, to Measure Methyl Mercury Accumulation in the Foodweb of the Sacramento-San Joaquin Delta Estuary*. Draft report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed. Central Valley Regional Water Quality Control Board and California Department of Fish and Game. Available at: http://loer.tamug.tamu.edu/calfed/DraftReports.htm.

Foe, C.G., Davis, J., Schwarzbach, M. Stephenson and S. Slotton, 2003. *Conceptual Model and Working Hypotheses of Mercury Bioaccumulation in the Bay-Delta Ecosystem and its Tributaries.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed. Central Valley Regional Water Quality Control Board, San Francisco Estuary Institute, U.S. Geological Survey, California Department of Fish and Game, and University of California. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Francesconi, K.A., R.C.J. Lenanton, N. Caputi and S. Jones. 1997. Long term study of mercury concentrations in fish following cessation of a mercury-containing discharge. *Marine Environmental Research*, 43(1): 27-40.

Gassel, M., S. Klassing, R.K. Brodberg and S. Roberts. 2005. *Fish Consumption Guidelines for Clear Lake, Cache Creek, and Bear Creek (Lake, Yolo, and Colusa Counties).* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Pesticide and Environmental Toxicology Section. Oakland, CA. January 2005. Available at: http://www.oehha.ca.gov/fish/so_cal/pdf_zip/ClearLake0105.pdf. Accessed: 23 August 2005.

Gill, G.A., K.Y. Choe, R. Lehman and S. Han. 2003. *Sediment-Water Exchange and Estuarine Mixing Fluxes of Mercury and Monomethyl Mercury in the San Francisco Bay Estuary and Delta*. Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 4B). Laboratory for Oceanographic and Environmental Research, Texas A&M University, Galveston, TX. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Gilmour C.C., E.A. Henry and R. Mitchell. 1992. Sulfate stimulation of mercury methylation in freshwater sediments. *Environmental Science & Technology*, 26: 2281-2285.

Gilmour C.C., G.S. Riedel, M.C. Ederington, J.T. Bell, J.M. Benoit, G.A. Gill, and M.C. Stordall. 1998. Methylmercury concentrations and production rates across a trophic gradient in the northern Everglades. *Biogeochemistry,* 40: 327-345.

Hamas, M.J. 1994. Belted kingfisher (*Ceryle alcyon*). *In:* The Birds of North America, No. 84. A. Poole and F. Gill (editors). Philadelphia: The Academy of Natural Sciences; Washington, D.C.: The American Ornithologists' Union.

Hatch, J.J. and D.V. Weseloh. 1999. Double-crested Cormorant (*Phalacrocorax auritus*). *In:* The Birds of North America, No. 441. A. Poole and F. Gill (editors). Philadelphia: The Academy of Natural Sciences; Washington, D.C., The American Ornithologists' Union.

Heim, W.A., K.H. Coale, and M. Stephenson. 2003. *Methyl and Total Mercury Spatial and Temporal Trends in Surficial Sediments of the San Francisco Bay-Delta.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed (Task 4A). California Department of Fish and Game Moss Landing Marine Laboratory. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm.

Heim, W. 2004. Personal communication between Wes Heim (Research Associate, Marine Pollution Studies Laboratory, Moss Landing Marine Laboratories) to Michelle Wood (Environmental Scientist, Central Valley Water Board), to develop a method to estimate methylmercury flux (load per acre) from wetlands and open-water areas in the Delta. Telephone and e-mail communications with attached example calculation file. December 2004.

Heim, W.A., E.R. Sassone, and K.H. Coale. 2004. Mono-Methylmercury production within the Bay-Delta. Abstract in *Northern California Chapter of the Society of Environmental Toxicology and Chemistry (SETAC), Hot Topics in Environmental Toxicology and Chemistry, 14th Annual Meeting, May 11-12, 2004, Davis, CA*. SETAC Press, pp: 18-19.

Herbold, B., A.D. Jassbay, and P.B. Moyle. 1992. *Status and Trends Report on Aquatic Resources in the San Francisco Estuary*. San Francisco Estuary Project. Oakland, CA.

Hintelmann, H. and R.D. Wilken. 1995. Levels of total and methylmercury compounds in sediments of the polluted Elbe River: Influence of seasonally and spatially varying factors. *Science of the Total Environment*, 166: 1-10.

Hornberger, M.I., S. Luoma, A. Van Geen, C. Fuller and R. Anima. 1999. Historical trends of metal in the sediment of San Francisco Bay, CA. *Marine Chemistry,* 64: 39-55.

Hoyer, M., R.W. Baldauf, C. Scarbro, J. Barres, and G.J. Keeler. 2002. Mercury emissions from motor vehicles. Paper in *13th International Emission Inventory Conference: Working for Clean Air in Clearwater*. June 8-10, 2004, Clearwater, FL. USEPA Office of Air Quality Planning and Standards and Emission Inventory Improvement Program (a partnership between USEPA, the State and Territorial Air Pollution Program Administrators and the Association of Air Pollution Control Officials). Available at: http://www.epa.gov/ttn/chief/conference/ei13/toxics/hoyer.pdf

Hrabik, T.R. and C.J. Watras. 2002 . Recent declines in mercury concentration in a freshwater fishery: isolating the effects of de-acidification and decreased atmospheric mercury in Little Rock Lake. *The Science of the Total Environment*, 297: 229-237.

Huber, K. 1997. *Wisconsin Mercury Sourcebook: A Guide to Help Your Community Identify & Reduce Releases of Elemental Mercury*. Wisconsin Department of Natural Resources, Bureau of Watershed Management. Madison, WI. May 1997. Available at: http://www.epa.gov/glnpo/bnsdocs/hgsbook/.

Hunerlach, M.P., J.J. Rytuba, and C.N. Alpers. 1999. Mercury Contamination from Hydraulic Placer-Gold Mining in the Dutch Flat Mining District, California. United States Geologic Survey (USGS). U.S. Geological Survey Water-Resources Investigations. Report 99-4018B, pp. 179-189

Hurley, J., J. Benoiit, C. Babiarz, M. Shafer, A. Andren, J. Sullivan, R. Hammond, and D. Webb. 1995. Influences of watershed characteristics on mercury levels in Wisconsin rivers. *Environmental Science & Technology*, 29: 1867-1875.

Hurley J., D.P. Krabbenhoft and L. Cleckner. 1998. System controls on the aqueous distribution of mercury in the northern Florida Everglades. *Biogeochemistry*, 40: 293-311.

Jackman, R.E., W.G. Hunt, J.M. Jenkins and P.J. Detrich. 1999. Prey of nesting bald eagles in Northern California. *Journal of Raptor Research,* 33:87-96.

James, L.A. 2004. Decreasing sediment yields in northern California: vestiges of hydraulic gold-mining and reservoir trapping. *Sediment Transfer through the Fluvial System. Proceedings of the Moscow Symposium, August 2004*. IAHS Publishers. 288 p. Available at: http://www.cla.sc.edu/geog/faculty/james/Research/Pubs/IAHS.James.pdf.

Jernelöv A, and B. Åséll. 1975. The Feasibility of Restoring Mercury-Contaminated Waters. *In*: Heavy Metals in the Aquatic Environment: An International Conference. P.A. Krenkel (editor). Oxford: Pergammon Press, Inc. pp. 299-309.

Johnson, B. and R. Looker. 2004. *Mercury in San Francisco Bay: Total Maximum Daily Load (TMDL) Proposed Basin Plan Amendment and Staff Report.* California Regional Water Quality Control Board, San Francisco Bay Region, staff report. April 30, 2004.

Jones & Stokes. 2001. *A Framework for the Future: Yolo Bypass Management Strategy*. Final report (J&S 99079) prepared for the CALFED Bay-Delta Program by the Yolo Bypass Working Group, Yolo Basin Foundation, and Jones & Stokes. August 2001. Available at: http://www.yolobasin.org/bypass_strategy.cfm.

Kelley, C., J. Rudd and M. Holoka. 2003. Effect of pH on mercury uptake by aquatic bacteria: Implications for mercury cycling. *Environmental Science & Technology*, 37: 2941-2946.

King J.K., S.M. Harmon, T.T. Fu and J.B. Gladden. 2002. Mercury removal, methylmercury formation, and sulfate reducing bacteria profiles in wetland mesocosms. *Chemosphere*, 46: 859-870.

Knowles, N., and D.R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. *Geophysical Research Letters*, 29(18): 38-1 to 38-4.

Krabbenhoft, D.P. and J.P. Hurley. 1999. The Sun's Detoxifying Effects on Mercury in the Everglades. Abstract in *U.S. Geological Survey Program on the South Florida Ecosystem – Proceedings of South Florida Restoration Science Forum, May 17-19, 1999, Boca Raton, FL*. S. Gerould and A. Higer (compilers). Tallahassee, Florida: U.S. Geological Survey Open-File Report 99-181, pp. 56-57. Available at: http://sflwww.er.usgs.gov/sfrsf/publications/proceedings/forumproceedings.pdf

Krabbenhoft, D.P., M. Olson, J. Dewild, D. Clow, R. Striegl, M. Dornblaser, and P. Vanmetre. 2002. Mercury loading and methylmercury production and cycling in high-altitude lakes from the Western United States. *Water, Air and Soil Pollution: Focus*, 2 (2): 233-249.

Krabbenhoft D.P., J.G. Wiener, W.G. Brumbaugh, M.L. Olson, J.F. Dewild and T.J. Sabinal. 1999. A National Pilot Study of Mercury Contamination of Aquatic Ecosystems along Multiple Gradients. *In*: U. S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, SC, March 8-12, 1999 – Volume 2 of 3 – Contamination of Hydrologic Systems and Related Ecosystems, Water-Resources Investigations Report: 99-4018B. D.W. Morganwalp and H.T. Buxton (editors). West 115 Trenton, N. J.: U. S. Dept. Interior, U. S. Geological Survey; Denver: Branch of Information Services (distributor); pp. 147-160. Available at: http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionB/2301_Krabbenhoft/pdf/2301_Krabbenhoft.pdf. Accessed: August 24, 2005.

Lawson, N.M. and R.P. Mason. 2001. Concentration of mercury, methylmercury, cadmium, lead, arsenic, and selenium in the rain and stream water of two contrasting watersheds in western Maryland. *Water Resources*, 35 (17): 4039-4052.

Leatherbarrow, J.E., L.J. McKee, D.H. Schoellhamer, N.K. Ganju and A.R. Flegal. 2005. *Concentrations and Loads of Organic Contaminants and Mercury Associated with Suspended Sediment Discharged to San Francisco Bay from the Sacramento-San Joaquin River Delta, California.* RMP Technical Report, prepublication manuscript. SFEI Contribution 405. San Francisco Estuary Institute. Oakland, CA. June 2005.

Lindeström, L. 2001. Mercury in Sediment and Fish Communities of Lake Vänern, Sweden: Recovery from Contamination. *Ambio*, 30: 538-544.

Lindeburg, M.R. 1992. *Civil Engineering Reference Manual*. Sixth Edition. Professional Publications, Inc.: Belmont, CA. Appendix A: Rational Method Runoff Coefficients.

Linthicum, J. 2003. Personal communications from Janet Linthicum (University of California Santa Cruz Predatory Bird Research Group) to Janis Cooke (Environmental Scientist, Central Valley Water Board) regarding nesting sites and prey remains for peregrine falcons in the Cache Creek, Napa valley and Delta areas. April 2003.

Lodenius, M. 1991. Mercury concentrations in an aquatic ecosystem during 20 years following abatement of the pollution source. *Water, Air, and Soil Pollution*, 56: 323-332.

LWA. 1996. *Sacramento NPDES Stormwater Discharge Characterization Program 1996 DCP Update Report.* Prepared by Larry Walker Associates (LWA) for the County of Sacramento, the City of Sacramento, the City of Folsom, and the City of Galt. September 1996.

LWA. 2002. Strategic Plan for the Reduction of Mercury-Related Risk in the Sacramento River Watershed. Appendix 1: Mercury Conceptual Model Report – Mercury Quantities, Fate, Transport, and Uptake in the Sacramento River Watershed. Prepared by Larry Walker Associates (LWA), Davis, California, for Delta Tributaries Mercury Council and Sacramento River Watershed Program. December 2002.

LWA. 2003. *Sacramento River Watershed Program Annual Monitoring Report: 2001–2002 (Final Draft).* Larry Walker and Associates (LWA). Davis, CA. June 2003.

Mallory, M. and K. Metz. 1999. Common merganser (*Mergus merganser*). *In:* The Birds of North America, No. 442. A. Poole and F. Gill (editors). Philadelphia: The Academy of Natural Sciences; Washington, D.C., The American Ornithologists' Union.

Marvin-DiPasquale, M.M., J. Agee, R.S. Oremland, M. Thomas, D.P. Krabbenhoft and C.G. Gilmour. 2000. Methylmercury Degradation Pathways- A comparison among three mercury impacted ecosystems. *Environmental Science & Technology*, 34: 4908-4916.

MASCO. 2008. Medical Academic and Scientific Community Organization (MASCO) Mercury Database. The Mercury Database was developed by MASCO with help from the Massachusetts Office of Technical Assistance for Toxics Use Reduction, Massachusetts Water Resources Authority, and Harvard University. Available at: http://www1.netcasters.com/cgi-bin/masco/mercury/view.pl

Mason, R.P., N.M. Lawson, and K.A. Sullivan. 1997. The concentration, speciation and sources of mercury in Chesapeake Bay Precipitation. *Atmospheric Environment,* 31 (21): 3541-3550.

Mason, R.P., W. Fitzgerald and F. Morel. 1994. The biogeochemical cycling of elemental mercury: Anthropogenic influences. *Geochimica et Cosmochimica Acta,* 58: 3191-3198.

Mason, R.P. and K.A. Sullivan. 1998. Mercury and methylmercury transport through an urban watershed. *Water Research*, 32 (2): 321-330.

McAlear, J.A. 1996. *Concentrations and fluxes of total mercury and methylmercury within a wastewater treatment plant.* Syracuse, NY: Syracuse University, Masters thesis, 79 p.

Miller, N.L., K.E. Bashford, and E. Strem. 2003. Potential impacts of climate change on California hydrology. *Journal of The American Resources Association,* August 2003: 771-784.

Miskimmin, B.M., J.W.M. Rudd and C.A. Kelly. 1992. Influences of dissolved organic carbon, pH, and microbial respiration rates on mercury methylation and demethylation in lake water. *Canadian Journal of Fish and Aquatic Sciences*, 49: 17-22.

Moyle, P. B. 2002. Inland Fishes of California. Revised and Expanded. Berkeley, CA: University of California Press.

NADP. 2004. National Atmospheric Deposition Program (NRSP-3). NADP Program Office, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820. Mercury Deposition Network available at: http://nadp.sws.uiuc.edu/mdn/.

NAS. 1973. *A Report of the Committee on Water Quality: Water Quality Criteria, 1972*. U.S. Environmental Protection Agency, National Academy of Science-National Academy of Engineers (NAS). EPA R3-73-033.

Nguyen, H.L., M. Leermakers, S. Kurunczi, L. Bozo, and W. Baeyens. 2005. Mercury distribution and speciation in Lake Balaton, Hungary. *Science of the Total Environment*, 340: 231-246.

Nichols, J., S. Bradbury, and J. Swartout. 1999. Derivation of wildlife values for mercury. *Journal of Toxicology and Environmental Health*: 325-355.

NRC. 2000. *Toxicological Effects of Methylmercury*. National Research Council, Committee on the Toxicological Effects of Methylmercury (NRC). Washington, D.C.: National Academy Press. Available at: http://www.nap.edu/books/0309071402/html.

OEHHA. 1994. *Health Advisory on Catching and Eating Fish. Interim Sport fish Advisory for San Francisco Bay.* California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Berkeley, CA. December 1994.

OEHHA. 1999. *California Sport Fish Consumption Advisories 1999*. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

OEHHA. 2000. *Evaluation of Potential Health Effects of Eating Fish from Black Butte Reservoir (Glenn and Tehama Counties): Guidelines for Sport Fish Consumption.* Draft Report. Pesticide and Environmental Toxicology Section, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. March.

OEHHA. 2006. *Draft Health Advisory for Fish and Shellfish From the Lower Cosumnes and Lower Mokelumne Rivers (Sacramento and San Joaquin Counties).* Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. April. Available at: http://www.oehha.org/fish/so_cal/pdf_zip/FactsDCosMo042806.pdf. Accessed September 2007.

OEHHA. 2007. *Draft Safe Eating Guidelines for Fish From the South Delta and San Joaquin River.* Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. March. Available at: http://www.oehha.org/fish/pdf/SJRSDfacts030907.pdf. Accessed September 2007.

Paquette, K. and G. Heltz, 1995. Solubility of cinnabar (red HgS) and implications for mercury speciation in sulfidic waters. *Water, Air and Soil Pollution*, 80: 1053-1056.

Parks, J.W. and A.L. Hamilton. 1987. Accelerating recovery of the mercury-contaminated Wabigoon/English River system. *Hydrobiologia*, 149: 159-188.

Parsons, T. and M. Takahashi. 1973. Biological Oceanographic Processes. New York: Pergamon Press, Inc., 186 p.

Peterson, S.A., J. Van Sickle, A.T. Herlihy, and R.M. Hughes. 2007. Mercury concentration in fish from streams and rivers throughout the western United States. *Environmental Science & Technology*, 41(1): 58-65.

Ravichandran, M., G.R. Aiken, J.N. Ryan and M.R. Reddy. 1998. Enhanced Dissolution of Cinnabar (mercuric sulfide) by Dissolved Organic Matter Isolated from the Florida Everglades. *Environmental Science & Technology*, 32: 33305-3311.

Regnell, O. and G. Ewald. 1997. Factors Controlling Temporal Variation in Methyl Mercury Levels in sediment and water in a seasonally stratified lake. *Limnology and Oceanography*, 42(8): 1784-1795.

Regnell, O., T. Hammar, A. Helgée and B. Trodesson. 2001. Effects of anoxia and sulfide on concentrations of total and methylmercury in sediment and water in two Hg-polluted lakes. *Canadian Journal of Fish and Aquatic Sciences*, 58: 506-517.

Regnell, O., A. Tunlid, G. Ewald and O. Sangfors. 1996. Methyl mercury production in freshwater microcosms affected by dissolved oxygen levels: role of cobalamin and microbial community composition. *Canadian Journal of Fish and Aquatic Sciences*, 53: 1535-1545.

Rudd, J.W.M., M.A. Turner, A. Furutani, A.L. Swick and B.E. Townsend. 1983. The English-Wabigoon River system: I. A synthesis of recent research with a view towards mercury amelioration. *Canadian Journal of Fish and Aquatic Sciences*, 40: 2206-2217.

Sassone, E.R., W.A. Heim, A. Byington, M. Stephenson, and K.H. Coale. 2004. *Methylmercury export from two experimental ponds on Twitchell Island, California.* Poster Presentation, Northern California Chapter of the Society of Environmental Toxicology and Chemistry (SETAC), Hot Topics in Environmental Toxicology and Chemistry, 14th Annual Meeting, May 11-12, 2004. Davis, CA.

Sassone, E.R., M.D. Stephenson, and K. Coale. 2006. *Methyl Mercury Production in Two California Delta Freshwater Ponds*. Abstract in: Fourth Biennial CALFED Bay-Delta Program Science Conference Abstracts, October 23-25, 2006, Sacramento, CA.

Schaffter, R.G. 1998. Growth of largemouth bass in the Sacramento-San Joaquin Delta. *IEP (Interagency Ecological Program) Newsletter*, 11(3): 27-30.

Schoellhamer, D.H. 1996. Time series of trace element concentrations calculated from time series of suspended solid concentrations and RMP water samples. U.S. Geological Survey, Sacramento. A special study of the San Francisco Estuary Regional Monitoring Program, San Francisco Estuary Institute. September 1996. Available at: http://www.sfei.org/sfeireports.htm.

Schroyer, T. 2003. Meeting with Tom Schroyer (Fisheries Biologist, California Department of Fish and Game, Bay-Delta Division), Janis Cooke (Environmental Scientist, CVRWQCB, Mercury TMDL Unit), and Michelle Wood (Environmental Scientist, CVRWQCB, Mercury TMDL Unit), on 29 April 2003 regarding delta creel surveys and observations of humans' fishing patterns on main and small channels throughout Delta region.

Schwarzbach, S. 2003. Personal communication from S. Schwarzbach (U.S. Geological Survey) to J. Cooke (Environmental Scientist, Central Valley Water Board) regarding presence of clapper rails and brown pelicans as occasional visitors to the Sacramento-San Joaquin River Delta. April 2003.

Schwarzbach, S., L. Thompson and T. Adelsbach. 2001. *An Investigation of Mercury Bioaccumulation in the Upper Cache Creek Watershed, 1997-1998.* USFWS Final Report.

U.S. Fish and Wildlife Service, Environmental Contaminants Division, Sacramento Fish and Wildlife Office. Off Refuge Investigations Report FFS #1130 1F22. DEC ID #199710005. July 2001.

Sellers, C., and C.A. Kelly. 2001. Fluxes of methylmercury to the water column of a drainage lake: The relative importance of internal and external sources. *Limnology and Oceanography,* 46: 623-631.

Sellers, C., C.A. Kelly, and J.W.M. Rudd. 1996. Photodegradation of methylmercury in lakes. *Nature,* 380: 694-697.

Service, R.F. 2004. As the West Goes Dry. *Science,* 303(5661): 1124-1127.

SFBRWQCB, 2006. *Mercury in San Francisco Bay. Adopted Basin Plan Amendment and Final Staff Report for Revised Total Maximum Daily Load (TMDL) and Mercury Water Quality Objectives*. San Francisco Bay Regional Water Quality Control Board, San Francisco. 9 August.

SFEI. 2000. *San Francisco Bay Seafood Consumption Study.* Final Report. San Francisco Estuary Institute. Richmond, CA.

SFEI. 2001. *San Francisco Bay Atmospheric Deposition Pilot Study Part 1: Mercury.* Prepared by the San Francisco Estuary Institute for the San Francisco Estuary Regional Monitoring Program, Oakland, CA. August 2001.

Shilling, F., L. Lippert and A. White. 2008. *Contaminated Fish Consumption in California's Central Valley Draft Report.* Dept. Environmental Science and Policy and Dept. Human and Community Development, University of California Davis. Report prepared for the Sacramento Regional County Sanitation District and the California Endowment. January.

Silver, E., J. Kaslow, D. Lee, S. Lee, M.L. Tan, E. Weis, and A. Ujihara. 2007. Fish consumption and advisory awareness among low-income women in California's Sacramento-San Joaquin Delta. *Environmental Research*, 104: 410-419.

SJ/SC. 2007. *San Jose/Santa Clara Water Pollution Control Plant Mercury Fate and Transport Study.* Environmental Services Department, San Jose/Santa Clara (SJ/SC) Water Pollution Control Plant. San Jose, CA. March 2007.

Slotton, D.G. and S.M. Ayers. 2001. Cache Creek Nature Preserve Mercury Monitoring Program, Yolo County, California, Second Semi-Annual Data Report, Spring-Summer 2001, prepared for Yolo County, California. November 2001.

Slotton, D.G., S.M. Ayers, T.H. Suchanek, R.D. Weyland, A.M. Liston, C. Asher, D.C. Nelson, and B. Johnson. 2003. *The Effects of Wetland Restoration on the Production and Bioaccumulation of Methylmercury in the Sacramento-San Joaquin Delta, California.* Final report submitted to the CALFED Bay-Delta Program for the project: An Assessment of the Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed. University of California, Davis, Dept. of Environmental Science and Policy, Dept. of Wildlife, Fish and Conservation Biology, and Division of Microbiology; U.S. Fish and Wildlife Service, Division of Environmental Contaminants. Available at: http://loer.tamug.tamu.edu/calfed/DraftReports.htm.

Slotton D.G., S.M. Ayers, T.H. Suchanek, R.D. Weyland, and A.M. Liston. 2004. *Mercury Bioaccumulation and Trophic Transfer in the Cache Creek Watershed, California, in Relation to Diverse Aqueous Mercury Exposure Conditions.* Subtask 5B. Final Report, University of California, Davis, Dept. of Env. Science and Policy and Dept. Wildlife, Fish and Conservation Biology. Prepared for the CALFED Bay-Delta Program, Directed Action #99-B06. Available at: http://loer.tamug.tamu.edu/calfed/FinalReports.htm. August.

Sommer, T.R., W.C. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries*, 26 (8): 6-16.

Southworth, G.R., R.R. Turner, M.J. Peterson, M.A. Bogle and M.G. Ryon. 2000. Response of mercury contamination in fish to decreased aqueous concentrations and loading of inorganic mercury in a small stream. *Environmental Monitoring and Assessment*, 63: 481-494.

SRWP. 2004. Microsoft Access database that compiles Sacramento River Watershed water quality data collected for the Sacramento River Watershed Program. Database provided by Larry Walker Associates (Claus Suverkropp) to Central Valley Regional Water Quality Control Board (Michelle Wood, Environmental Scientist, Sacramento).

St. Louis, V., J. Rudd, C. Kelly, K. Beaty, N. Bloom, and R. Flett. 1994. Importance of wetlands as sources of methyl mercury to boreal forest ecosystems. *Canadian Journal of Fish and Aquatic Sciences*, 51: 1064-1076.

St. Louis, V., J. Rudd, C. Kelly, K. Beaty, R. Flett, and N. Roulet. 1996. Production and loss of methylmercury and loss of total mercury from boreal forest catchments containing different types of wetlands. *Environmental Science & Technology,* 30: 2719-2729.

Stephenson, M., B. Sohst, and S. Mundell. 2002. *Mercury Lagrangian Study Between Colusa and Hamilton City*. Draft final report prepared for the Sacramento Regional County Sanitation District. Marine Pollution Studies Labs, California Department of Fish and Game, and Moss Landing Marine Labs. January 2002.

Stephenson, M.D., K. Coale, G. Gill, C.S. Enright, and J.R. Burau. 2006. *Methyl Mercury Import/Exports in Wetlands in the San Francisco Delta and Tributaries - A Mass Balance Assessment Approach.* Abstract in: Fourth Biennial CALFED Bay-Delta Program Science Conference Abstracts, October 23-25, 2006, Sacramento, CA.

Stephenson, M., C. Foe, G.A. Gill, and K.H. Coale. 2007. T*ransport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment Approach*. CalFed Mercury Project Annual Report. April 2, 2007.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger. 2004. Changes in Snowmelt Runoff Timing in Western North America Under a 'Business as Usual' Climate Change Scenario. *Climatic Change,* 62: 217-232, 2004.

Storer, R.W., and G.L. Nuechterlein. 1992. Western Grebe and Clark's Grebe. *The Birds of North America*, 26: 1-15

Stratton, J.W., D.F. Smith, A.M. Fan, and S.A. Book. 1987. *Methyl Mercury in Northern Coastal Mountain Lakes: Guidelines for Sport Fish Consumption for Clear Lake (Lake County), Lake Berryessa (Napa County), and Lake Herman (Solano County).* State of California Department of Health Services, Hazard Evaluation Section and the Epidemiological Studies and Surveillance Section, Community Toxicology Unit, Office of Environmental Health Hazard Assessment. Berkley, CA. Fish Advisory Report. April 1987. Available at: http://www.oehha.ca.gov/fish/pdf/CLEARLAKEREPORT.pdf

Suits, B. 2000. Delta Island Consumptive Use Model Delta-wide island consumptive use estimates for October 1998 through September 1999. Provided by Bob Suits (Department of Water Resources, suits@water.ca.gov) to Chris Foe (Central Valley Water Board) *via* email on 7 November 2000.

Sveinsdottir, A.Y. and R.P. Mason. 2005. Factors controlling mercury and methylmercury concentrations in largemouth bass (*Micropterus salmoides*) and other fish from Maryland reservoirs. *Archives of Environmental Contamination and Toxicology*, 49: 528–545.

Sweet, C. 2000. Personal communication between Clyde Sweet (National Atmospheric Deposition Program, Associate Coordinator for Toxics) and Janis Cooke (Central Valley Water Board) regarding use of the Mercury Deposition Network data to estimate total atmospheric deposition of mercury to a lake near Covelo, CA. Additional information available at: http://nadp.sws.uiuc.edu/mdn/.

SWRCB. 1995. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. 95-1WR. Sacramento, California. 45 p.

SWRCB. 2007. *State Water Resources Control Board Resolution No. 2007-0045 Approving an Amendment to the Water Quality Control Plan for the San Francisco Bay Region to Establish Mercury Fish Tissue Objectives, Vacate a Mercury Water Quality Objective, and Establish a Total Maximum Daily Load (TMDL) for Mercury in San Francisco Bay*. Sacramento, 17 July.

SWRCB-DWQ. 1990. *1990 Water Quality Assessment*. April 4, 1990. State Water Resources Control Board, Division of Water Quality (SWRCB-DWQ). Sacramento, California. 89 p.

SWRCB-DWQ. 2002. Toxic Substances Monitoring Program: Freshwater Bioaccumulation Monitoring Program: Data Base. State Water Resources Control Board, Division of Water Quality. Available at: http://www.waterboards.ca.gov/programs/smw/index.html

SWRCB-DWQ. 2003. *Revision of the Clean Water Act Section 303(d) List of Water Quality Limited Segments, Final Staff Report, Volume I.* State Water Resources Control Board, Division of Water Quality (SWRCB-DWQ). February 2003.

Takizawa, Y. 2000. Minamata disease in retrospect. *World Resource Review*, 12(2): 211-223.

Tetra Tech, Inc. 2005a. *Guadalupe River Watershed Mercury TMDL Project Final Conceptual Model Report.* Prepared by Tetra Tech, Inc., Research and Development, Lafayette, CA. Prepared for San Francisco Bay Regional Water Quality Control Board. 20 May 2005. 160 p.

Tetra Tech, Inc. 2005b. *Sacramento River Flood Control System*. Map prepared by Tetra Tech, Inc., based on November 2003 Department of Water Resources (DWR) maps of levees maintained by DWR, reclamation, levee, and drainage districts and municipalities. Map included in the administrative record for the Sacramento River Watershed Model completed in spring 2005.

Tetra Tech, Inc. 2006. *Technical Review of Delta Mercury TMDL.* Prepared for the Delta Mercury TMDL Collaborative. Lafayette, CA. 12 December.

Turner, R.R. and G.R. Southworth. 1999. Mercury-contaminated industrial and mining sites in North America: an overview with selected case studies. *In*: Mercury Contaminated Sites: Characterization, Risk Assessment, and Remediation. R. Ebinghaus, R.R. Turner, L.D. de Lacerda, O. Vasiliev and W. Salomons (editors). SpringerVerlag: Heidelberg, pp. 89-108.

Ujihara, A. 2006. Personal communications between Alyce Ujihara (Research Scientist, California Department of Health Services Environmental Health Investigations Branch) and Janis Cooke (Environmental Scientist, Central Valley Water Board) regarding results of the

Delta-San Joaquin River Pilot Angler Survey Oct-Nov 2005 and other public outreach information. January-June.

USACE. 2002. “Moisture Content,” personal communication from L. Fade, U.S. Army Corps of Engineers (USACE) to G. Collins, San Francisco Bay Regional Water Quality Control Board, October, as cited in Johnson and Looker, 2004.

USEPA. 1987. Integrated Risk Information System. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment. Washington, D.C. January 31, 1987. (First File-On-Line) Available at: http://www.epa.gov/iris/subst/0073.htm . Last revised: July 27, 2001. Accessed: June 27, 2005.

USEPA. 1995a. *Great Lakes Water Quality Initiative Technical Support Document for Wildlife Criteria.* U.S. Environmental Protection Agency, Office of Water (USEPA). EPA-820-B-95-009. March 1995.

USEPA. 1995b. Trophic Level and Exposure Analyses for Selected Piscivorous Birds and Mammals, Volume II: Analyses of Species in the Coterminous United States. Washington, D.C., Office of Water

USEPA. 1995c. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 1: Fish Sampling and Analysis. Second Edition. Washington, D.C., U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology. EPA-823-R-95-007.

USEPA. 1997a. *Mercury Study Report to Congress Vol. 6: An Ecological Assessment for Anthropogenic Mercury Emissions in the United States.* U.S. Environmental Protection Agency (USEPA), Office of Air Quality Planning and Standards and Office of Research and Development, Washington, D.C. EPA-452/R-97-008.

USEPA. 1997b. *Mercury Study Report to Congress Vol. 7: Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States.* U.S. Environmental Protection Agency (USEPA), Office of Air Quality Planning and Standards and Office of Research and Development.

USEPA. 2000a. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000).* Office of Science and Technology, Office of Water. Washington, D.C. EPA-822-B-00-004. October.

USEPA. 2000b. *Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California; Rule.* U.S. Environmental Protection Agency (USEPA). Code of Federal Regulations, Title 40, Part 131, Section 38. In *Federal Register*: May 18, 2000 (Volume 65, No. 97), Rules and Regulations, pp. 31681-31719.

USEPA. 2001*. Water Quality Criterion for Protection of Human Health: Methylmercury*. U.S. Environmental Protection Agency, Office of Science and Technology (USEPA). EPA-823-R-01-001. January 2001.

USEPA. 2006. Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA, et al., No. 05-5015, (April 25, 2006) and Implications for NPDES Permits. Memorandum from Benjamin H. Grumbles (Assistant Administrator) to the Directors of the Office of Ecosystem Protection (Region 1), Division of Environmental Planning and Protection (Region 2), Water Divisions (Regions 3-7 and 9), Office of Ecosystems Protection and Remediation (Region 8), and Office of Environmental Cleanup (Region 10). November 15, 2006. Available at: http://www.epa.gov/owow/tmdl/dailyloadsguidance.html.

USFWS. 2002. *Comments on the Clear Lake Total Maximum Daily Load (TMDL) for Mercury – Draft Final Report.* Letter from Michael B. Hoover, Acting Assistant Field Supervisor, U.S. Fish and Wildlife Service (USFWS), to Janis Cooke, Environmental Scientist, Central Valley Regional Water Quality Control Board (FWS/EC-02-026). 8 April 2002.

USFWS. 2003. *Evaluation of the Clean Water Act Section 304(a) Human Health Criterion for Methylmercury: Protectiveness for Threatened and Endangered Wildlife in California.* U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Environmental Contaminants Division. October 2003.

USFWS. 2004. *Evaluation of Numeric Wildlife Targets for Methylmercury in the Development of Total Maximum Daily Loads for the Cache Creek and Sacramento-San Joaquin Delta Watersheds.* U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Environmental Contaminants Division. March 2004.

USFWS. *2006. Classification of Wetlands and Deepwater Habitats of the United States.* WETDBA.CONUS_wet_poly.shp [GIS shapefile]. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Available: http://wetlandsfws.er.usgs.gov/imf/imf.jsp?site=extract_tool. Using: ArcGIS [GIS software], Version 9.2, Redlands, CA: Environmental Systems Research Institute, Inc., 1999-2006.

USGS. 2003. Microsoft Excel Spreadsheets of unpublished data for Bear River Mercury Cycling Project. Data provided by USGS (Charlie Alpers, Research Chemist) to Central Valley Regional Water Quality Control Board (Michelle Wood, Environmental Scientist, Sacramento).

Verdon, R., D. Brouard, C. Demers, R. Lalumiere, M. Laperle and R. Schetagne. 1991. Mercury evolution (1978-1988) in fishes of the La Grande Hydroelectric Complex, Quebec, Canada. *Water, Air, and Soil Pollution*, 56: 405-417.

Wallschläger, D., M.V.M. Desai, M. Spengler and R.D. Wilken. 1998. Mercury speciation in floodplain soils and sediments along a contaminated river transect. *J. Environmental Quality*, 27:1034-1044.

Weast, R. (editor). 1981. *CRC Handbook of Chemistry and Physics*. Second Edition. Boca Raton, FL: CRC Press, Inc, pp. B-205 and B-206.

Weir, W.W. 1952. *Soils of San Joaquin County, California.* California Soil Survey, Inventory of Soil Resources. University of California, College of Agriculture, Agricultural Experiment Station, Berkeley 4, California. June 1952.

Wiener, J.G., C.C. Gilmour and D.P. Krabbenhoft. 2003a. *Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration.* Draft Final Report to CALFED for Contract 4600001642 between the Association of Bay Area Governments and the University of Wisconsin-La Crosse, 28 February 2003.

Wiener, J.G., Krabbenhoft, D.P. Heinz, G.H., and Scheuhammer, A.M. 2003b. Ecotoxicology of Mercury, Chapter 16. *In* Handbook of Ecotoxicology, 2nd Edition. D.J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr. (editors). Boca Raton, Florida: CRC Press, pp. 409-463.

Wiener, J.G. and D.J. Spry. 1996. Toxicological Significance of Mercury in Freshwater Fish (Chapter 13). *In*: Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations. SETAC Special Publication. W.N. Beyer, G.H. Heinz and A.W. Redmon-Norwood. Boca Raton: CRC Press, Inc, pp. 297-339.

Willits, N. 2005-2006. Statistical consultation provided by Neil Willits, Ph. D. (Senior Statistician, University of California, Davis, Department of Statistics, Statistical Laboratory) to Greg Marquis (Engineering Geologist, Central Valley Water Board), to develop a method to calculate confidence limits for annual average mercury mass loading estimates based on daily flows and concentration data. E-mail communications with attached example calculation files, November 2005 through February 2006.

Wolfe, M.F., S. Schwarzbach and R.A. Sulaiman. 1998. Effects of mercury on wildlife: A comprehensive review. *Environmental Toxicology and Chemistry*, 17:146-60.

Wright, S.A. and D.H. Schoellhamer. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. *San Francisco Estuary and Watershed Science* [online serial], May 2004 issue, Article 2. Available at: http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art2

Wright, S.A. and D.H. Schoellhamer. 2005. Estimating sediment budgets at the interface between rivers and estuaries with application to the Sacramento – San Joaquin River Delta. Pre-publication manuscript. May 2005. 53 p.